TARDEC

---TECHNICAL REPORT---

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Compressible Fluid Suspension Performance Testing

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ABSTRACT

Mobility testing was conducted on two HMMWVs at the U.S. Army Yuma Proving Grounds by the U.S. Army Tank-automotive Research, Development and Engineering Center (TARDEC), and Davis Technologies International, Inc. (DTI) of Addison, Texas during the period of 23-27 September 2002. One of the vehicles tested was a standard HMMWV and the second was a HMMWV with a very low bandwidth active compressible fluid suspension system that was designed and installed on the vehicle by DTI. The purpose of the tests was to evaluate the possible performance benefits of the compressible fluid suspension system. Ride quality performance was quantified over three separate cross-country courses. Each vehicle's driver limited speed was also measured over discrete half-round obstacles of 4, 6, and 8-inch heights.

Vehicle maneuverability was also evaluated by testing over a lane-change course and a slalom course at a variety of vehicle speeds. Limited vehicle roll down tests were also conducted to get a comparison of the rolling resistance of the two vehicles.

INTRODUCTION

This report documents the testing of a very low bandwidth active compressible fluid suspension (CFS) on a High Mobility Multi-purpose Wheeled Vehicle (HMMWV) as shown in Figure 1. The vehicle modifications and testing were conducted under TARDEC CRADA 03-01 (Cooperative Research and Development Agreement) with Davis Technologies International, Inc. Under this CRADA, DTI designed and fabricated a compressible fluid suspension strut and the associated control system. DTI also installed the system on a government furnished HMMWV and worked with government personnel to perform vehicle shakedown testing. TARDEC then sponsored the formal mobility testing of the modified HMMWV (along with a similar stock HMMWV) at Yuma Proving Grounds (YPG) in Yuma, Arizona.

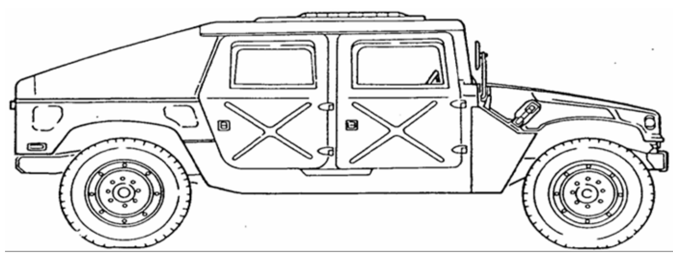

Figure 1 - High Mobility Multi-Purpose Wheeled Vehicle (HMMWV)

The use of compressible fluids as a spring and damping medium for the suspension systems on heavy mining trucks began in the 1980s. The motivating factor involving these early applications was to reduce the frame loads and stresses on these extremely heavily loaded vehicles. The application of compressible fluid struts to these mining trucks greatly reduces many of the frame cracking problems that had been occurring with the use of conventional suspension systems.

Additional efforts by DTI over the past decade to further develop the CFS for broader applications have included systems on the following vehicles; a High Speed Engineering Vehicle (HSEV) for the Australian Defense Industries; a Light Armored Vehicle (the LAV 25) for the David Taylor Research Center; a military HMMWV for AM

General, a commercial Hummer; a crash fire-rescue vehicle; a large prototype electric bus; and the Propulsion System Demonstrator for the Naval Surface Warfare Center. More recently, DTI has teamed with Arvin Meritor to produce an independent CFS for the Multi-Drive FCV (Future Cargo Vehicle).

Several key design features of the CFS led to the interest at TARDEC to further explore the CFS technology. The use of a single strut to include the spring, damping, and actuation functions offered the potential to save both weight and volume over conventional suspension systems. On the Multi-Drive FCV, the standard coil-over-shock units were replaced with DTI CFS ride struts at a weight savings of 95 lbs per wheel.

The response of a CFS strut is also quicker than that of a hydropneumatic system because the CFS system doesn't require a hydraulic flow in order to respond to load and shock impulses. The compressible fluid design also permits the use of higher damping power than does a hydropneumatic system and thus is extremely well suited to severe, high-speed cross-country applications. The use of a compressible fluid actuator design also permits the actuator to be moved through its total stroke with the movement of a relatively small amount of fluid. This is because the fluid displaced is proportional to the rod size for the compressible strut, but is proportional to the cylinder bore size for the hydraulic strut.

LOW BANDWIDTH ACTIVE COMPRESSIBLE FLUID SUSPENSION

Under the CRADA with DTI described above, the government furnished HMMWV was initially outfitted with a set of simple passive compressible fluid struts. This modified HMMWV was driven extensively, both on and off road, and performed quite impressively. It was decided, however, to upgrade the suspension prior to formal testing of the system at Yuma Proving Grounds. DTI had been pursuing similar systems for other vehicles that included simple height management systems, low bandwidth active systems, and some work on a high frequency fully active system.

It was opted under the CRADA to implement a low bandwidth version of the compressible fluid suspension on the government furnished HMMWV. This would include full suspension height management capability as well as providing some measure of ride quality and roll control enhancement over the passive compressible system, which was being upgraded. It was felt that the height management system alone was worth the added complexity since it would allow the full designed suspension travel for all vehicle-loading situations. The enhancements in ride quality and roll control were also considered to be desirable goals, but lack of funding precluded a thorough analysis program to choose the system response and authority properties to best advantage.

The resulting compressible fluid suspension system (referred to as CFS herein) is shown in Figure 2 mounted on the government HMMWV.

Figure 2 - Compressible Fluid HMMWV

In the front and rear CFS strut configuration views, it can be observed that the single compressible fluid strut is mounted similarly to the original HMMWV shock absorber. This strut acts as the spring, shock absorber, and actuator and requires no additional spring. In addition, the CFS suspension permitted the removal of the sway bar from the HMMWV resulting in even further weight savings. It is the HMMWV with this low-bandwidth active compressible fluid suspension system that is the subject of the test results in this report and is referred to as the CFS HMMWV.

TEST PLAN

The U.S. Army Tank-automotive Research and Development Center has long been involved in the development and evaluation of advanced suspension technologies. The major focus of these efforts is to increase the cross-country mobility performance of combat vehicles while not degrading the vehicle's stability and maneuverability. The objective of this formal testing was to quantify the relative performance, in terms of ride quality, shock response, and maneuverability, of the compressible fluid suspension with respect to a comparative HMMWV with a passive suspension system. The specific tests designed to produce these quantities are summarized below with the full description of the test plan included in Appendix A.

RIDE QUALITY

The performance criterion for ride quality is based on absorbed power. Absorbed power is a measure of a human's tolerance to vibration. The absorbed power theory was developed, tested, and quantified in the late 60s at TACOM and is recorded by Lee and Pradko (1968), Lins (1972), Pradko et. al. (1965), Pradko et. al. (1966) and reviewed by Smith et.al. (1978). Absorbed power is a time average of frequency weighted root-mean-square (rms) accelerations. The recognized (documented in references cited above) ride limiting absorbed power for an average driver was determined to be approximately 6 watts for a medium short duration (maybe 3-10 minutes).

For this program three separate ride quality courses were used at YPG. These courses are labeled as RMS courses 3, 4, and 5 and have corresponding roughness indices of 1.5, 2.0, and 3.4 inches rms. The general layout of the RMS courses is shown in Appendix A - figure A1. The courses are hard packed gravel and are maintained and periodically resurveyed by YPG to maintain their roughness content. A photograph of RMS course 5 is shown in Figure 3.

Figure 3 - Terrain RMS Course 5 at YPG

Each vehicle (the CFS and the passive HMMWV) was run over a course at as near a constant speed as possible. The vertical acceleration was recorded at the base of the driver's seat and directly below the driver's torso. This vertical acceleration was then used to compute the driver's vertical absorbed power for that speed over that course. Generally the course was run in both directions at the same speed and the two drivers' absorbed powers were averaged. (Note that the absorbed power theory includes input for the driver's pitch and roll motion's and for the driver's feet. The criterion most generally used, however, employs only the driver's vertical absorbed power.) The vehicle speed is gradually increased on subsequent runs down the course to provide an accurate estimate of the vehicle driver's ride limiting speed on that course (i.e. the speed at which the driver received 6 watts of vertical absorbed power). This procedure is completed for courses with a variety of roughness levels and the ride limiting speed is plotted as a function of surface roughness.

SHOCK QUALITY

The vehicle's shock transmission performance is based on the peak vertical acceleration measured at the base of the driver's seat. The driver's acceleration is measured over a series of rigid half-round obstacles of increasing height. The general layout of the bump course used in the shock test is shown in Appendix A - figure A2. The course is a concrete surface with the appropriate half round obstacle bolted in place on the course. Each obstacle is traversed at increased vehicle speeds until the driver's shock limit is exceeded. The driver's shock limit is set at 2.5 g's, and the speed at which he experiences this 2.5 g limit is recorded for each obstacle. A plot of the 2.5 g shock limiting speed versus half-round obstacle height is then used to quantify the vehicle's shock performance.

MANEUVERABILITY

Maneuverability is defined here as the ability to safely execute various turning requirements at reasonable speeds. The maneuvers that are used to evaluate the maneuverability are the lane change and the slalom courses depicted in Appendix A - figures A3 and Appendix A - figure A4 respectively. The performance on these courses is measured in terms of the vehicle's roll motion and lateral acceleration as a function of vehicle velocity. A specific limit is not ascribed to these vehicle performance measures, but the relative performance between the CFS HMMWV and the passive HMMWV can be made from the resulting data. The vehicle is driven through the courses at a constant speed (as near as possible) and the roll and lateral motions are recorded (as well as the steering input). The minimum and maximum values of roll rate and lateral acceleration are recorded for each vehicle speed that is run. This is done for both vehicle concepts and the results are plotted as a function of vehicle velocity.

VEHICLE SETUP AND INSTRUMENTATION

The compressible fluid suspension was installed by DTI on a government furnished HMMWV model M1025. This M1025 had a decal curb weight of 5960 lbs and a GVW of 8200 lbs. The stated cg height was 33.1 inches. This low-bandwidth active HMMWV was shipped to YPG for instrumentation.

The passive HMMWV, supplied by YPG, for comparison testing was a model M1037. This M1037 had a listed curb weight of 5424 lbs and a GVW of 8660 lbs. The listed height of the c.g. for this vehicle was 28.4 inches.
Ballast was added to both of the HMMWVs to give them each approximately the same total weight and to also keep them comparable to the results of the earlier

electromechanical (EM) active suspension tests described by Bylsma (2000). The individual wheel loadings for the CFS and the passive HMMWVs are shown in Figures 4 and 5

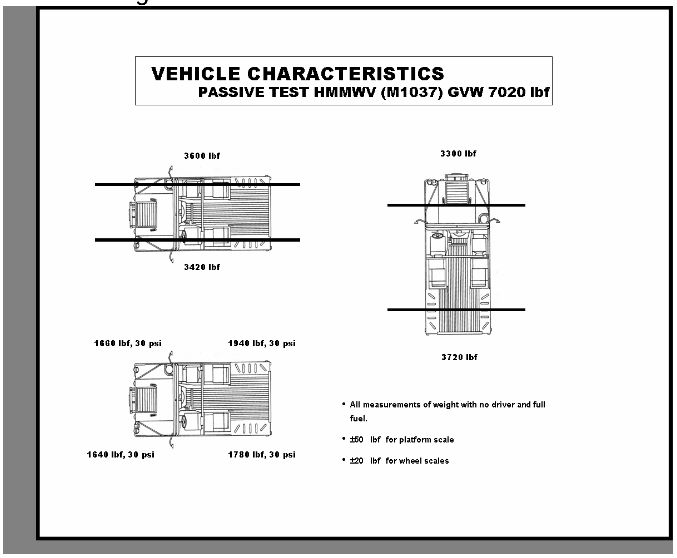

Figure 4 – Passive HMMWV Loads

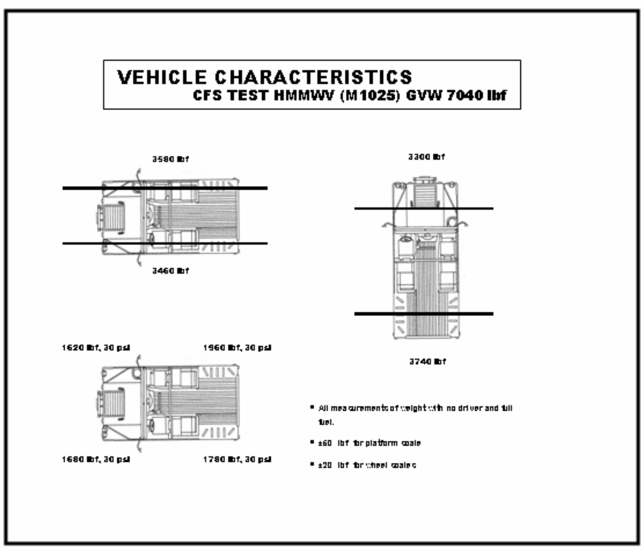

Figure 5 - CFS HMMWV Loads

YPG personnel instrumented both vehicles. The details of the particular sensors used are included in Appendix C. The three angular rates and linear accelerations were recorded at approximately the cg of the chassis. An additional tri-axial accelerometer was mounted at the hub of the right front wheel to assess wheel accelerations, particularly over the half-round obstacles. A separate vertical accelerometer was also mounted at the frame cross member behind the driver's seat to be used in driver's shock and ride quality performance measurement. Suspension travel was also measured for each wheel with a string potentiometer. And finally a steering angle sensor and a vehicle speed sensor were included. The steering sensor data from the passive vehicle was also filtered with a 10 Hz low-pass filter because of excessive noise in the signal.

The data was sampled at 500 Hz for all runs except the half-round obstacle shock tests. The data for these tests was sampled at 1000 Hz. An anti-aliasing filter was also used with the wheel hub tri-axial accelerometer for the shock tests. The filter had a low pass-band frequency of 400 Hz and a stop-band of 497.5 Hz.

TEST PROGRAM

The testing was conducted at Yuma Proving Grounds (YPG) during the week of 23-27 September 2002. The complete test matrix is included as Appendix B. The test program utilized two professional test drivers from YPG and generally alternated vehicles and drivers in the test sequence (note the test matrix does not maintain the exact chronology of test runs for the passive and active systems within a given test). Generally speaking, the less severe tests, in terms of possible damage to vehicle hardware, were run first. Thus the slalom tests were run first, followed by the lane change tests, the rms ride quality tests were run next, and finally the half-round bump shock tests were run last.

Overall the hardware performed very well throughout the testing. The use of removable data collection cards necessitated periodic pauses in the testing to allow for off loading and spot-checking of the collected data to ensure the continued operation of all the sensors and the data acquisition system. One string potentiometer was damaged during the testing and was replaced in the field. Also a small leak of one CFS strut occurred. The leak was cleaned up and the strut was inspected. It was determined that the strut was fine and no further leaking was observed from the strut.

RESULTS

The minimum and maximum sensor values were recorded for each test run and are included in Appendix D. There are two lines (or rows) representing each sensor for each test run. The first row is the maximum value (e.g. frntx or frnty) and the second row label is appended with an "n" and contains the minimum value recorded for that run (e.g. frntxn or frntyn). The sensors are listed in the same order as in the sensor list in Appendix C and the orientations and units for each signal are also recorded there. The only exception to the above description is for the "Road Speed" signal (Channel # 11 in Appendix B). The minimum and maximum values of road speed are not included since each test run was run while trying to hold a constant road speed. The last two rows of Appendix D, however, contain the average road speed (in mph) and total recorded run time (in seconds) for each test run.

A more complete statistical analysis was also run for each ride quality test over the measured cross-country (or

"rms") courses. This statistical analysis was performed on the driver's vertical acceleration signal. A synopsis of these results is included in Appendix E for each "rms" test run. The driver's vertical rms acceleration (in g's) is included here, as well as the average speed of the run and the driver's vertical absorbed power (in watts). The driver's vertical absorbed power values are used as the basis for the ride quality curves described below.

Ride Quality Performance

Three separate ride quality courses were exercised for this portion of the testing. These YPG courses are labeled RMS3, RMS4, and RMS5 and have surface roughness levels of 1.5, 2.0, and 3.4 inches rms respectively. These ride quality courses are predominately pitch-plane courses (i.e. they do not induce vehicle roll motion). Several different signals were considered of interest for the rms course tests. In the following plots the more severe of the two directions (north or south) at each speed is reported.

The vertical wheel accelerations that might typically be seen in cross-country operation were one such signal. The front right wheel hub was fitted with a tri-axial accelerometer and Figures 6-8 show the maximum and minimum vertical wheel accelerations for each of the test runs.

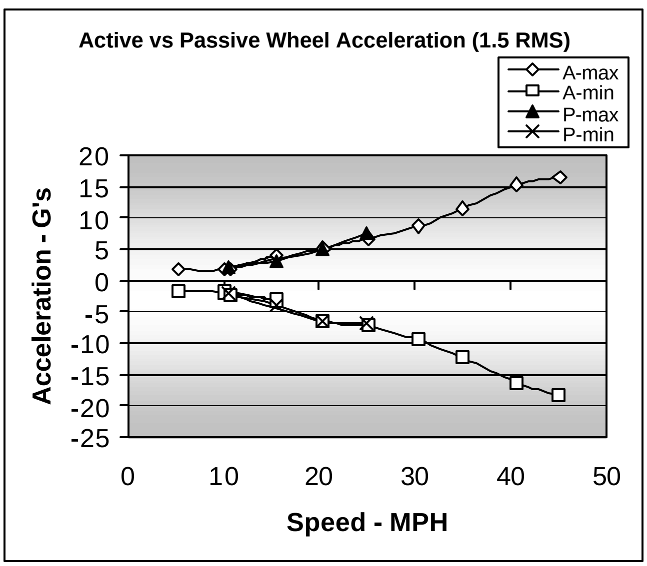

Figure 6- Passive Wheel Acceleration (1.5 RMS)

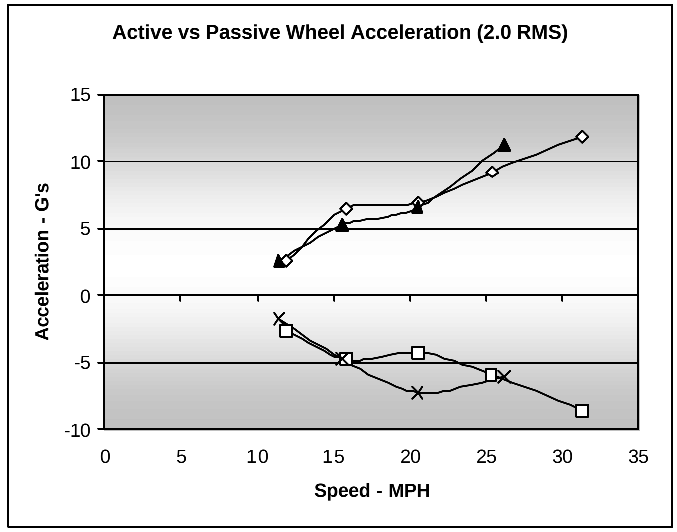

Figure 7- Passive Wheel Acceleration (2.0 RMS)

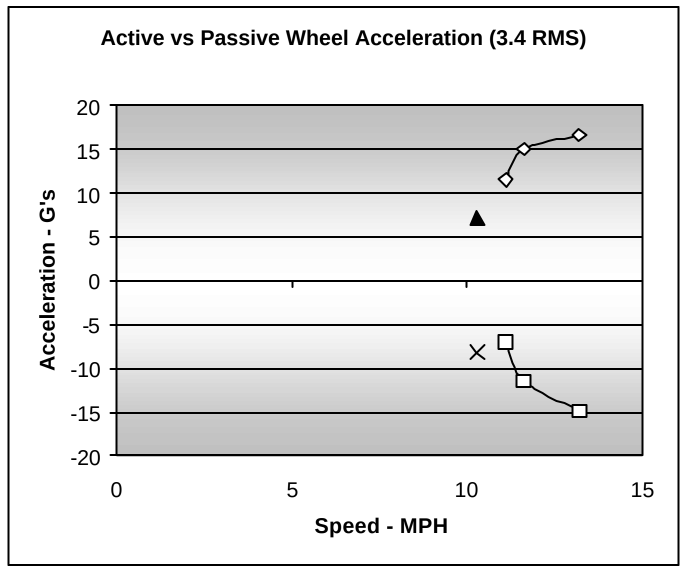

Figure 8 - Passive Wheel Acceleration (3.4 RMS)

Each figure contains the acceleration data as a function of vehicle speed for both vehicle concepts over one of the three rms courses. There is not a significant difference between the peak wheel acceleration levels for the two vehicles, but at the more extreme speeds, vertical accelerations of over 15 g's were recorded. Figure 9 gives further insight into the behavior of the right front wheel over the rms courses.

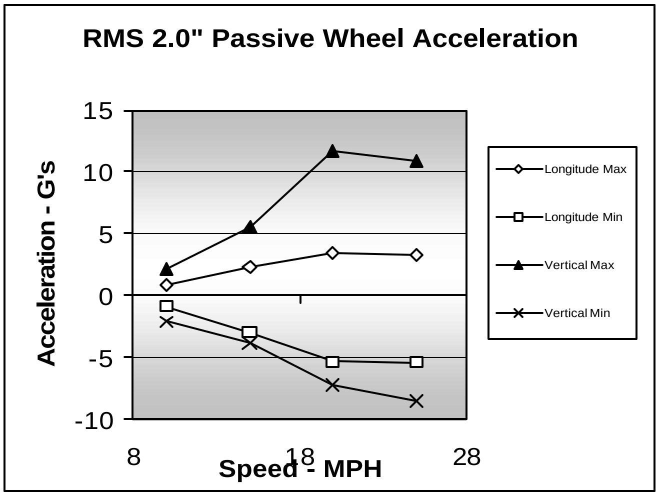

Figure 9 - Passive Wheel Acceleration Extremes

This curve shows the longitudinal and the vertical acceleration extremes for the passive HMMWV over the 2.0 inch rms course when run in the south direction. It can be seen that significant longitudinal tire forces are present in the system.

Suspension travel was also investigated for both vehicles over the rms courses. Since the courses were not designed to induce vehicle roll, the suspension travel was analyzed only for the right side of the vehicles. Figures 10-13 show the minimum and maximum suspension travel experienced for the active and the passive vehicles over the 1.5" and 2.0" rms course (the 3.4" course had a very limited number of runs on it). It is interesting to note that the rear suspension travel on the passive HMMWV didn't appear to be as fully used as it was on the active system.

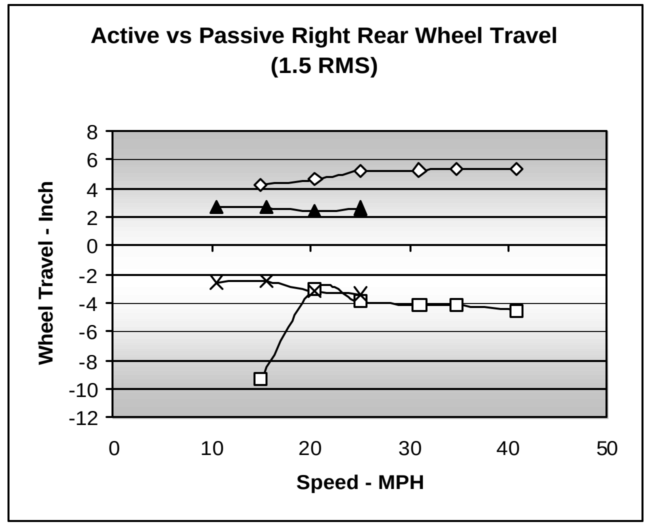

Figure 10 - Right Rear Wheel Travel (1.5 RMS)

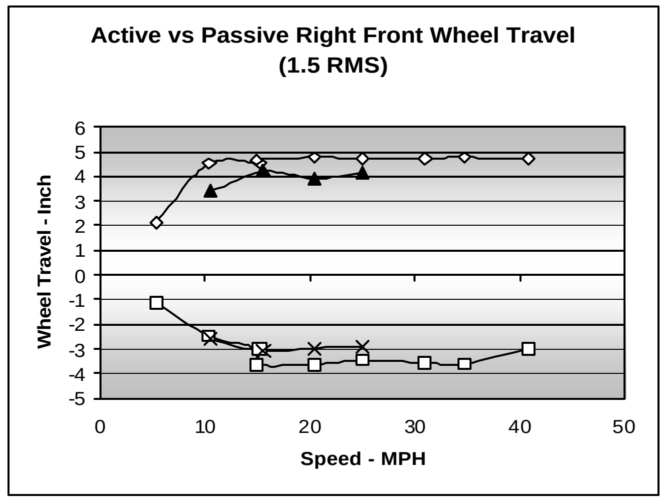

Figure 11 - Right Front Wheel Travel (1.5 RMS)

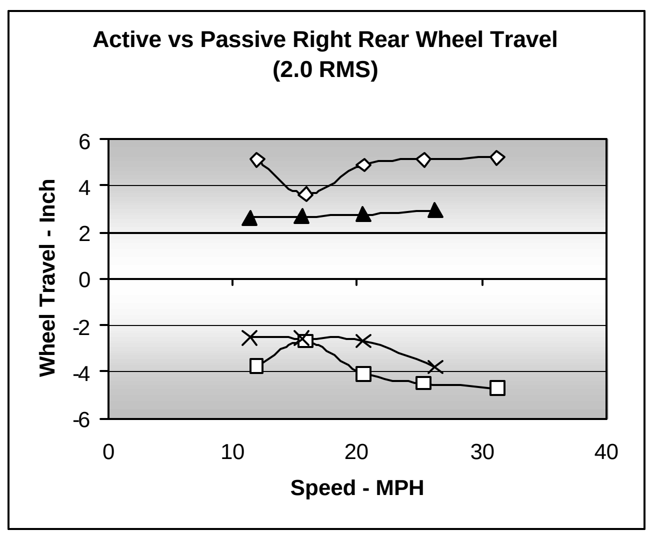

Figure 12 - Right Rear Wheel Travel (2.0 RMS)

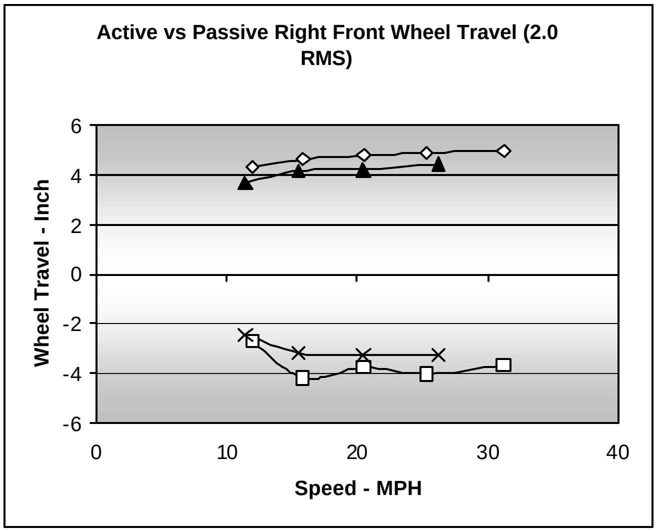

Figure 13 - Right Front Wheel Travel (2.0 RMS)

It is interesting to note that the peak chassis cg vertical accelerations, shown in Figures 14-16, do not increase drastically with vehicle speed as do the driver's vertical absorbed power discussed below. Since the driver's seat is quite near the longitudinal cg, this would tend to indicate that the rms accelerations rise more with vehicle speed than does the peak value of the same acceleration signal.

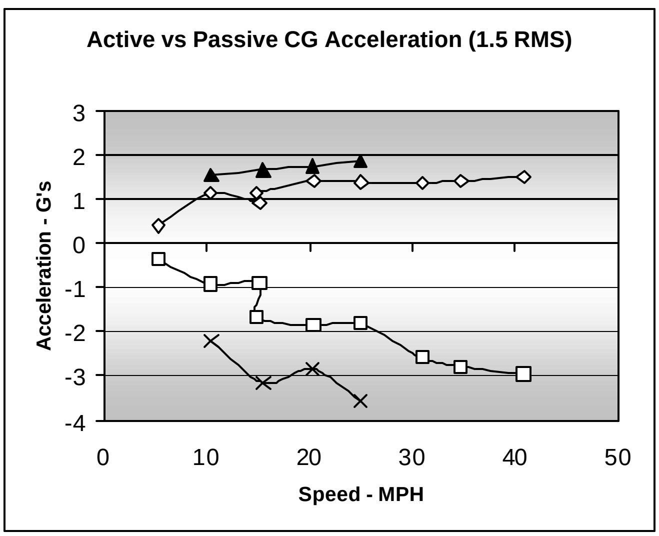

Figure 14 - Peak CG Accelerations (1.5 RMS)

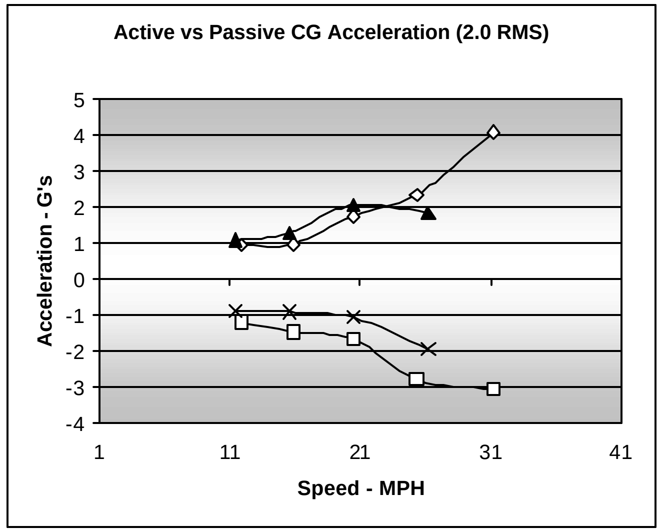

Figure 15 - Peak CG Acceleration (2.0 RMS)

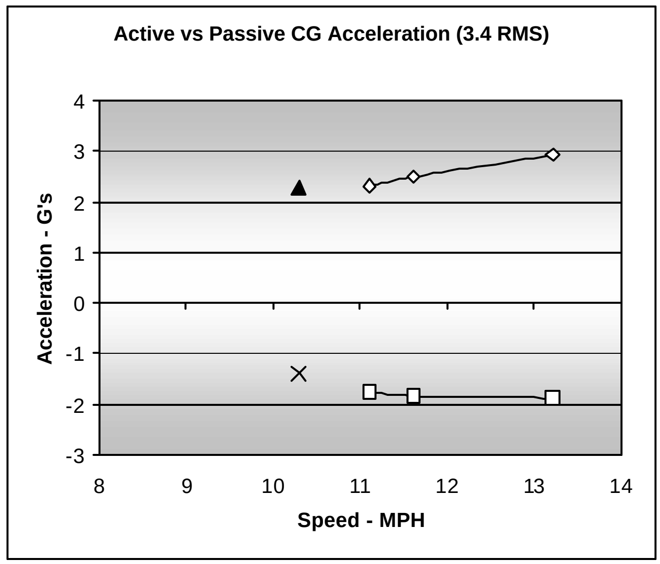

Figure 16 - Peak CG Acceleration (3.4 RMS)

Figures 17-19 give the maximum and minimum chassis pitch rates for the active and the passive systems for each course. The pitch motion is consistently a little lower for the active HMMWV than for the passive system.

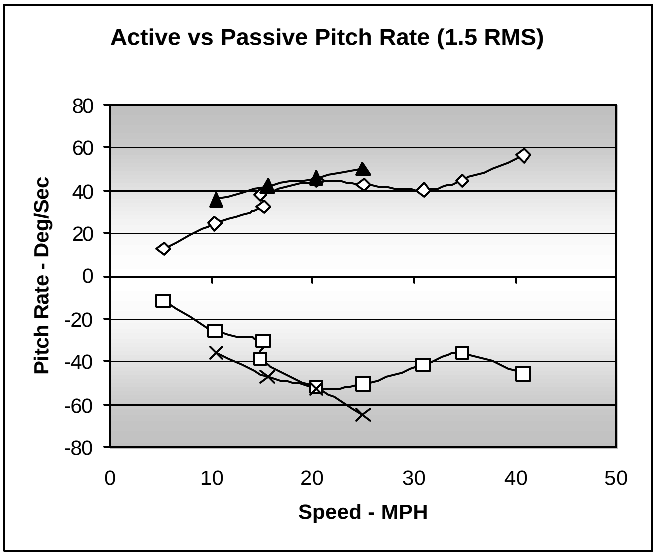

Figure 17 - Peak Pitch Rates (1.5 RMS)

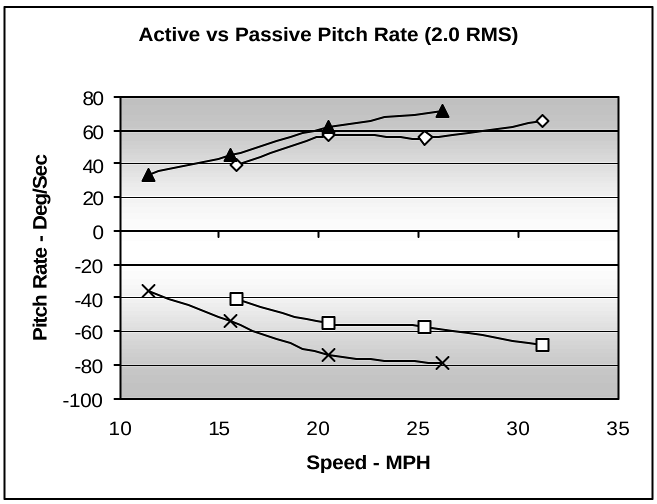

Figure 18 - Peak Pitch Rates (2.0 RMS)

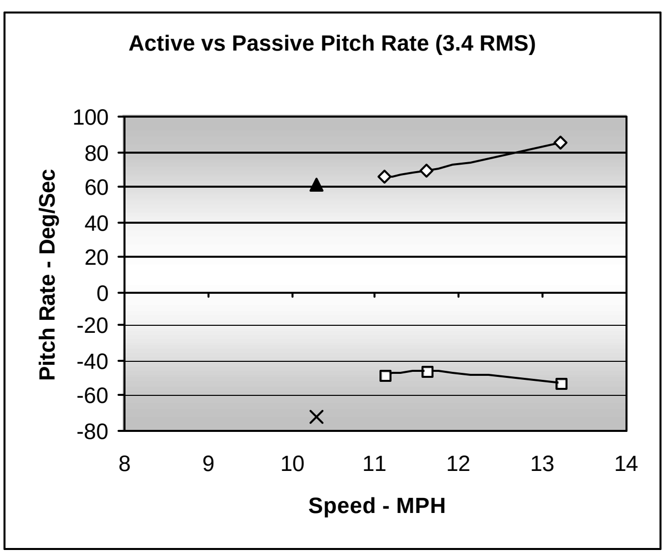

Figure 19 - Peak Pitch Rates (3.4 RMS)

The ride quality of a vehicle is quantified in terms of the vehicle speeds over different rms courses at which the vehicle's driver would experience 6 watts of vertical absorbed power. The driver's vertical acceleration for each rms course run was calculated and the results are plotted separately for the passive and the active HMMWVs over each of the three rms courses. These plots are shown in Figures 20-25. Each of these figures contains separate plots for the runs made in each of the two directions across the respective course. In general, it can be seen that the two directions produced quite similar absorbed power values. The two runs were averaged and an interpolated value was calculated (except for the passive HMMWV over the 3.4" rms course where extrapolation was employed based on the other absorbed power curves) for the 6 watt ride limiting speed over each terrain.

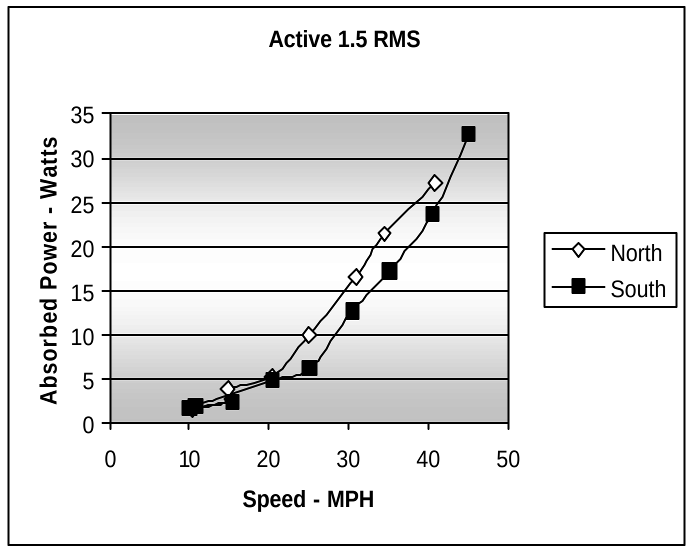

Figure 20 - Active 1.5 RMS

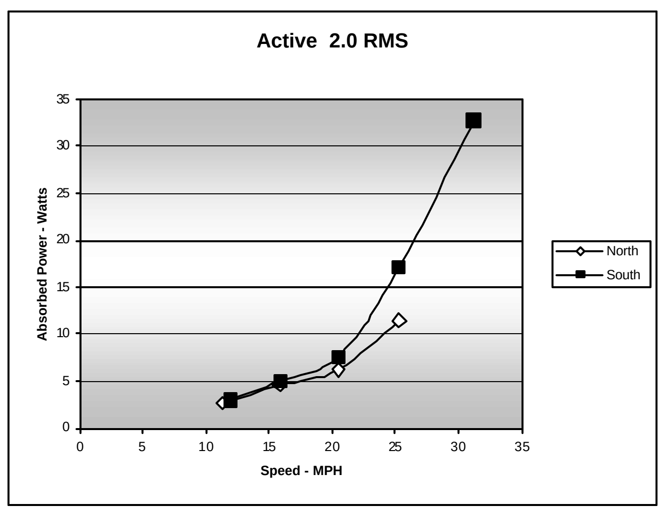

Figure 21 - Active 2.0 RMS

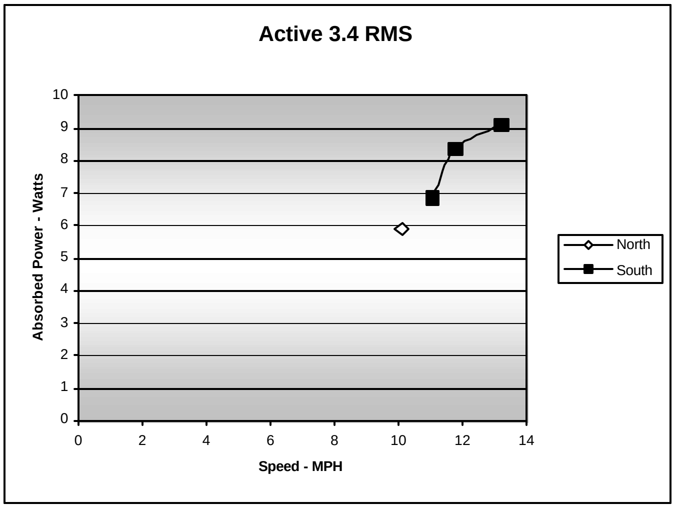

Figure 22 - Active 3.4 RMS

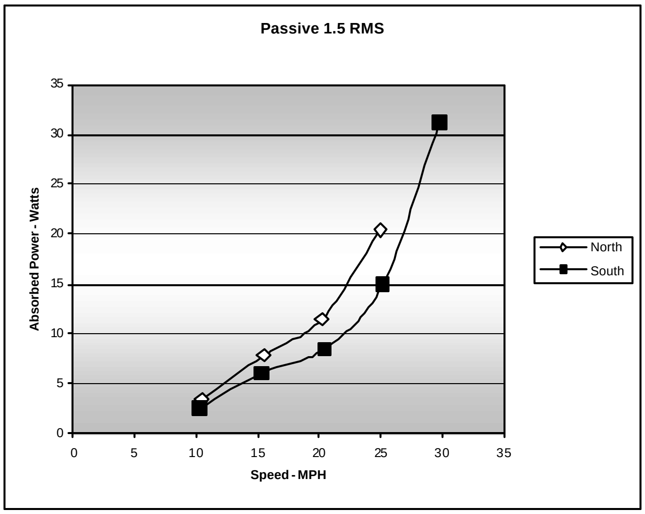

Figure 23 - Passive 1.5 RMS

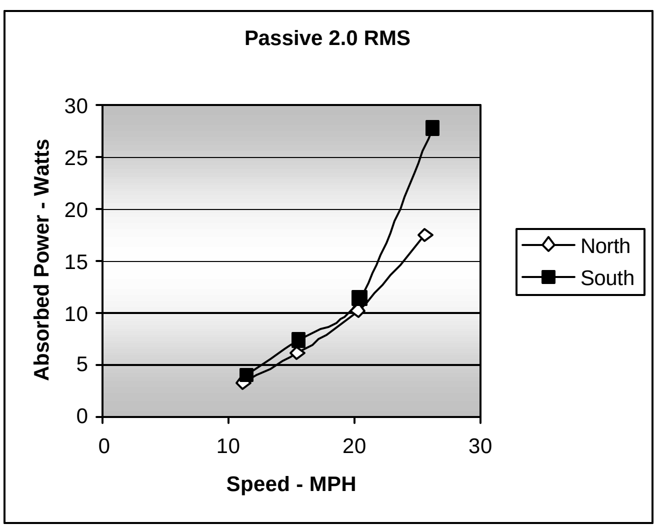

Figure 24 - Passive 2.0 RMS

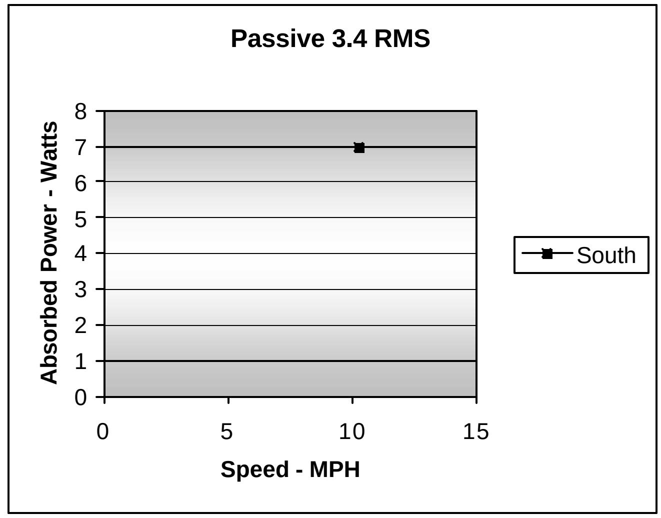

Figure 25 - Passive 3.4 RMS

The resulting ride limiting speed curves for the active and the passive HMMWVs are then shown in Figure 26. A fairly significant increase in ride limiting speed can be seen here for the low-bandwidth active compressible fluid HMMWV over the passive HMMWV. The 1.5" rms terrain yielded about a 60% improvement for the active CF system, whereas the slightly rougher 2.0" rms course showed about a 35 % increase in ride limiting speed. Only about a 15% increase in ride limiting speed was obtained over the more severe 3.4" rms course.

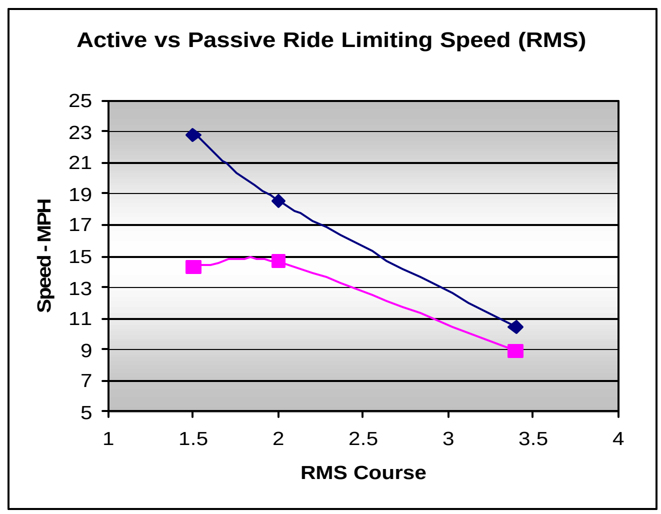

Figure 26 - Ride Limiting Speed

It should be noted that the passive HMMWV was not the same model as the active HMMWV which somewhat clouds the comparison. The passive HMMWV that was used in the active Electromechanical Suspension (EMS) testing over the same rms courses showed a couple of mph less for its ride limiting speed over both the 2.0" and the 3.4" rms courses (Bylsma 2000). These differences further compound the problem of comparing the active

EMS performance to that of the CFS system despite the use in both cases of the HMMWV and the YPG courses.

Shock Performance

The shock testing is based on the driver’s tolerance to a single vertical acceleration input. The limiting shock level of vertical acceleration for the driver is considered to be 2.5 g’s. The vehicle was tested over 4, 6, and 8 inch high, half round obstacles. The obstacles were made by cutting steel pipe in half lengthwise, and welding the half-round obstacles to steel plates. The half-round obstacles were bolted down on a concrete test area. Each obstacle was then negotiated at increasing speed until it was felt the shock was too severe to increase the speed further. Since the half round obstacles apparently present a more severe shock environment than the rms courses do, it was desirable to compare the wheel peak accelerations over the two types of courses. Figures 27-29 show the peak wheel vertical and longitudinal accelerations as a function of vehicle velocity for each of the three bump heights tested over.

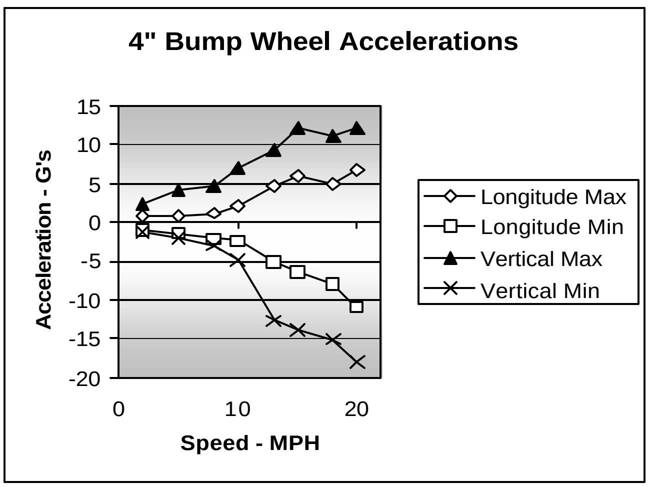

Figure 27 - 4" Bump Wheel Accelerations

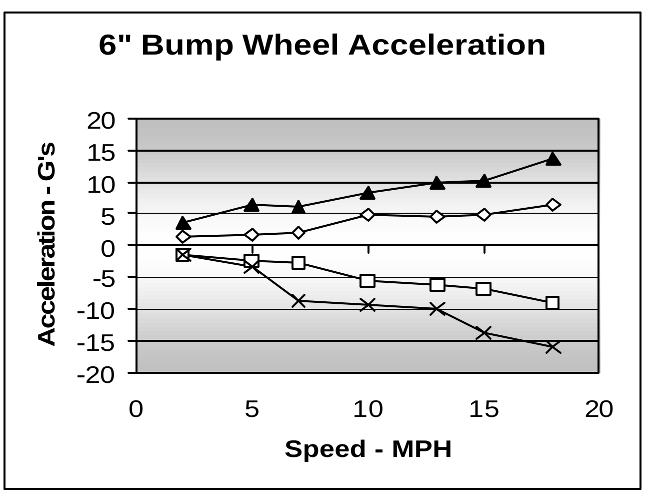

Figure 28 - 6" Bump Wheel Accelerations

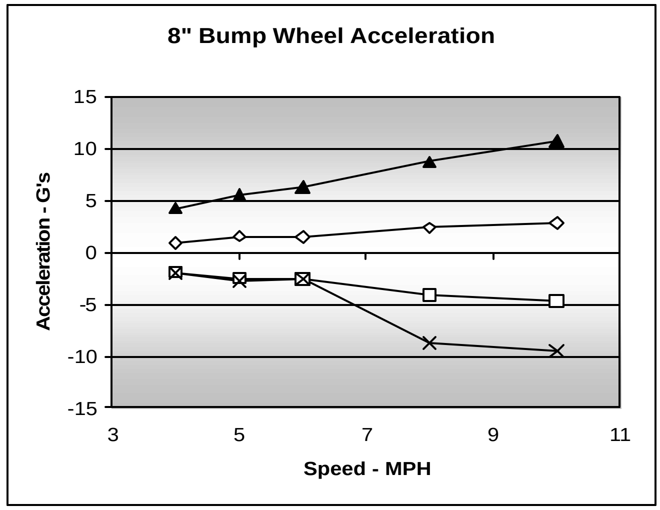

Figure 29 - 8" Bump Wheel Accelerations

Figures 30-32 record the driver’s vertical acceleration versus vehicle speed for each of the three obstacle heights. These plots show a significant reduction in driver’s acceleration between the low bandwidth active CF HMMWV and the passive HMMWV.

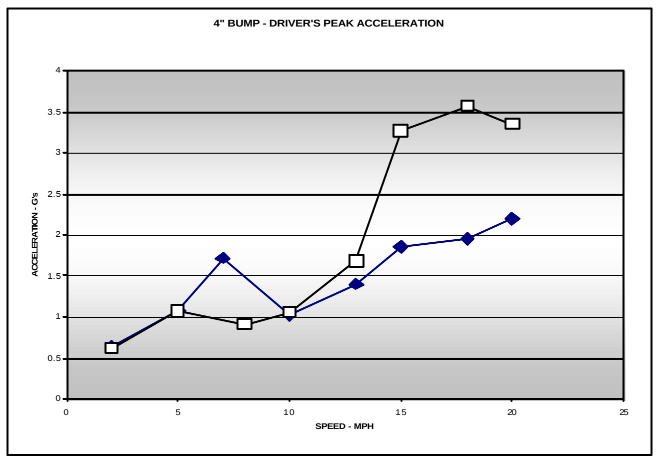

Figure 30 - 4" Bump Driver's Acceleration

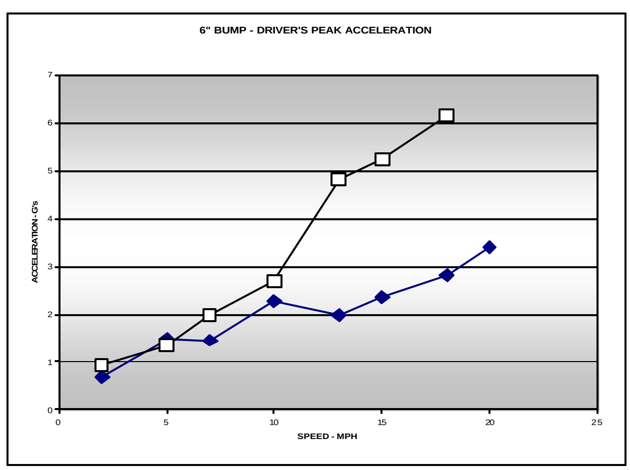

Figure 31 - 6" Driver's Acceleration

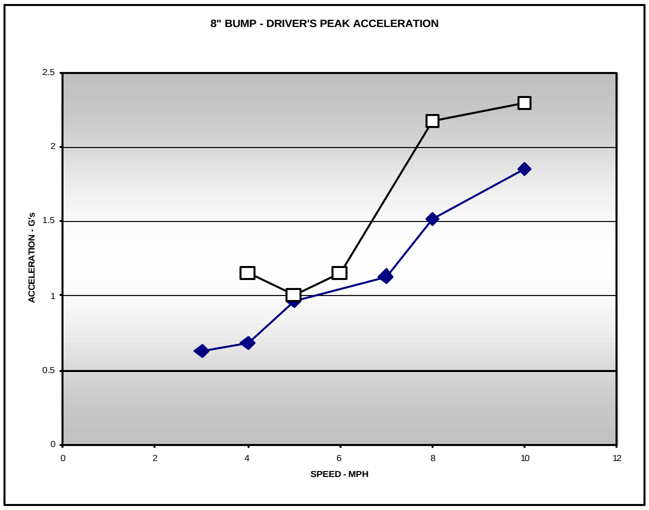

Figure 32 - 8" Driver's Acceleration

This improvement is summarized in Figure 33. The shock limiting speed is improved by about 60% on the 4" bump and by 30-40% on the 6 and 8-inch obstacles.

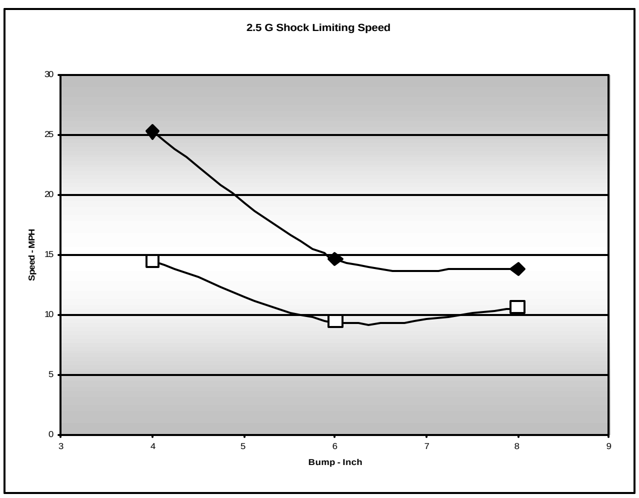

Figure 33 - 2.5 G Shock Limiting Speed

Maneuverability Performance

The maneuverability of the low-bandwidth CF active and the passive HMMWV was compared based on slalom and lane change maneuvers as described earlier. Since these two tests exercise the vehicles in essentially the same manner, only the results of the lane change tests are reported here. The signals of interest for these tests were taken to be the suspension travel at each wheel, the chassis lateral acceleration, the chassis roll rate and roll angle, the chassis yaw rate, and the steering command angle. Further, since the lane change maneuver involves both a left and a right turn of approximately equal severity, only the suspension (or wheel) travel on the left side of the vehicle is considered. For each of the signals of interest, plots are included for the minimum and maximum signal levels experienced in each of the constant speed runs of the active and the passive HMMWVs.

Figures 34-35 record the extremes of suspension travel as a function of vehicle speed for the active and the passive vehicles. The wheel travel is consistently greater for the active system than for the passive system.

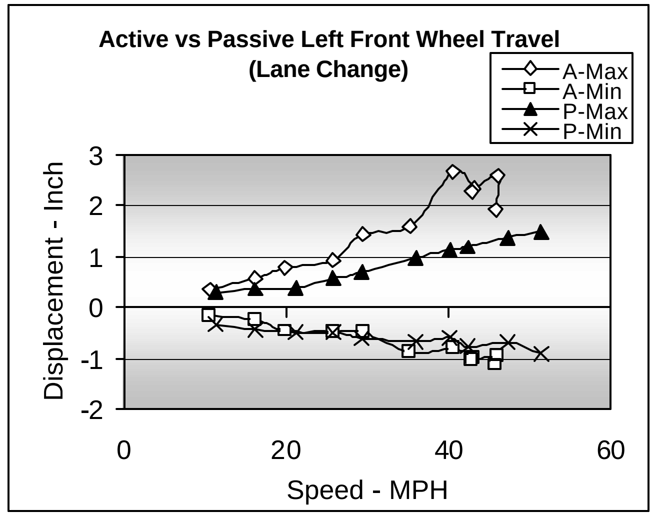

Figure 34 - Left Front Wheel Travel (Lane Change)

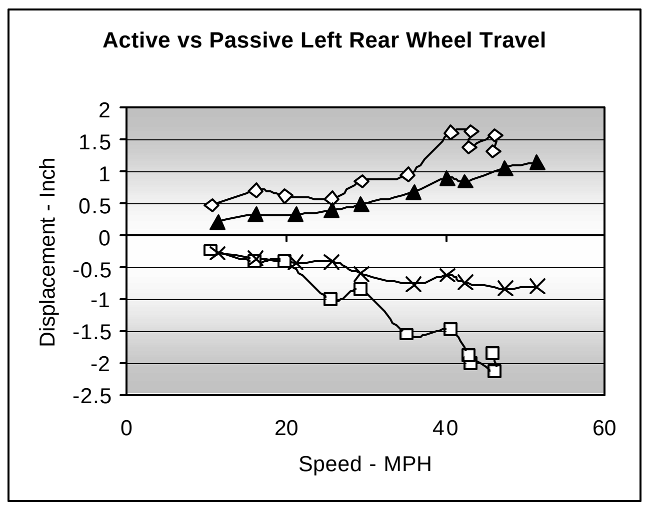

Figure 35 - Left Rear Wheel Travel (Lane Change)

This fact is reinforced by the corresponding extremes of chassis roll angle and roll rate signals recorded in Figures 36-37. At about 45 mph, for example, the CFS HMMWV experienced about an 8 degree total range of roll motion, whereas the passive HMMWV rolled only about 5 degrees (from the minimum to the maximum values).

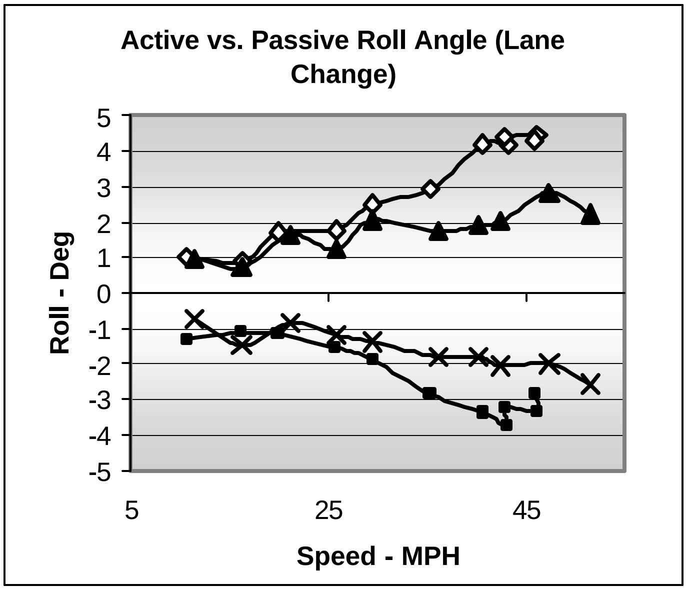

Figure 36 - Roll Angle (Lane Change)

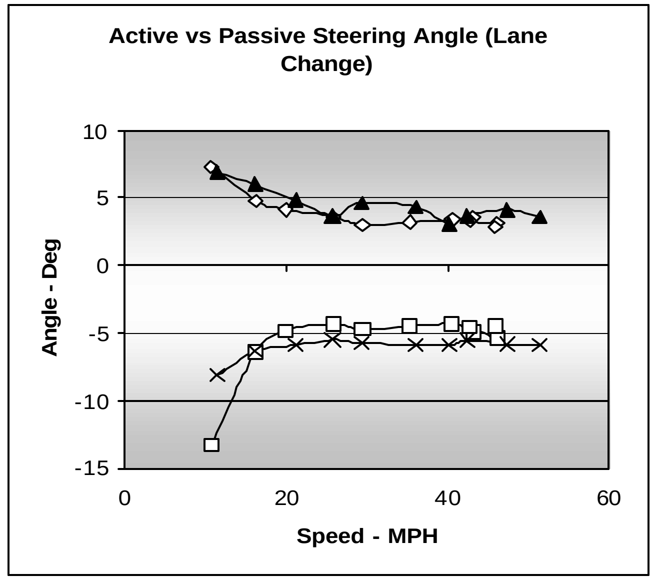

Figure 38 - Steering Angle (Lane Change)

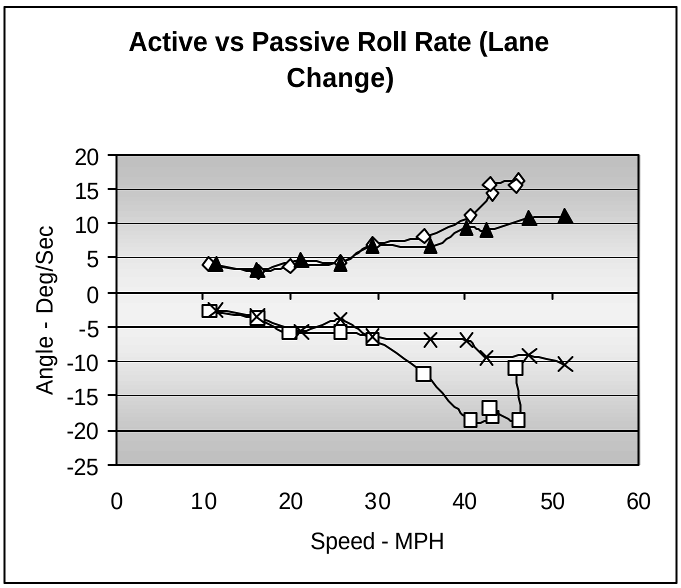

Figure 37 - Roll Rate (Lane Change)

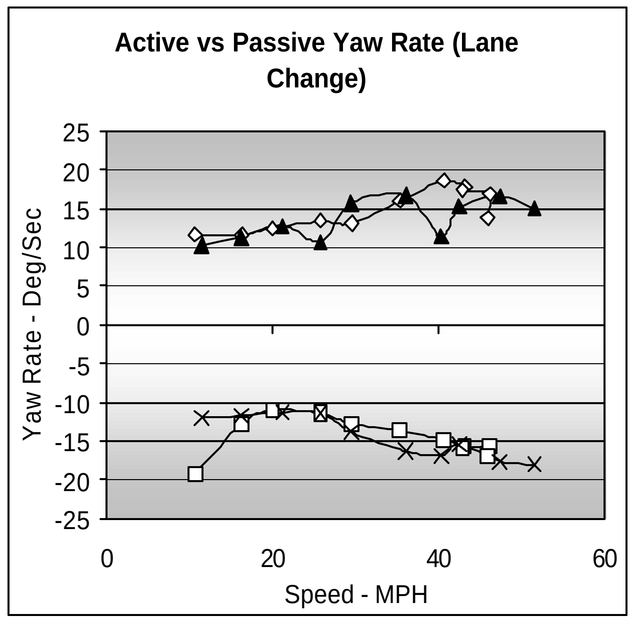

Figure 39 - Yaw Rate (Lane Change)

Figures 38-39 record the minimum and maximum values for the steering command and the resulting vehicle yaw rate for each test run.

The lateral acceleration of the active and passive systems is shown in Figure 40. Once again the passive system has a somewhat better performance than does the active.

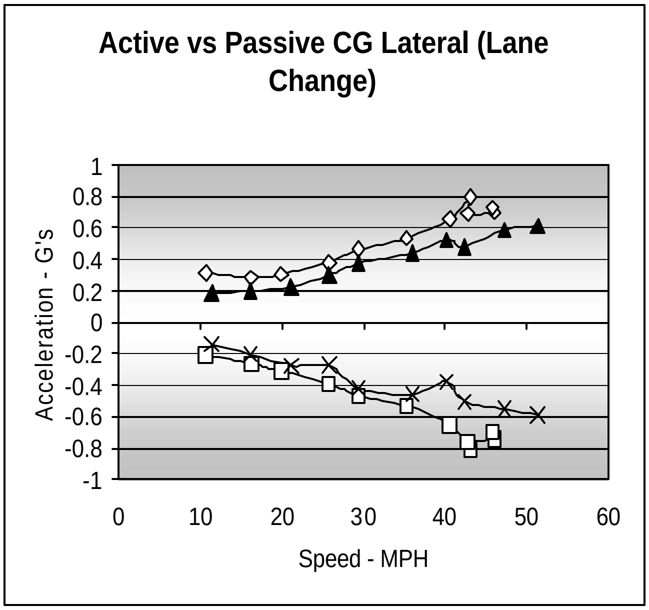

Figure 40 - CG Lateral Acceleration (Lane Change)

A couple of comments concerning the lane change performance of the low-bandwidth active CF system are in order. It should be noted that the cg height of the M1025 HMMWV was 33.1 inches whereas the cg height for the M1037 HMMWV was listed as 28.4 inches. This 4.7 inch difference in cg height would certainly affect the chassis motion in the lane change maneuvers. Also the anti-roll bar was removed from the active HMMWV. It is conjectured that additional active suspension authority and an enhanced controller that considered the vehicle turning command and possibly yaw and roll angle, could significantly alter these results for test vehicles with similar cg positions.

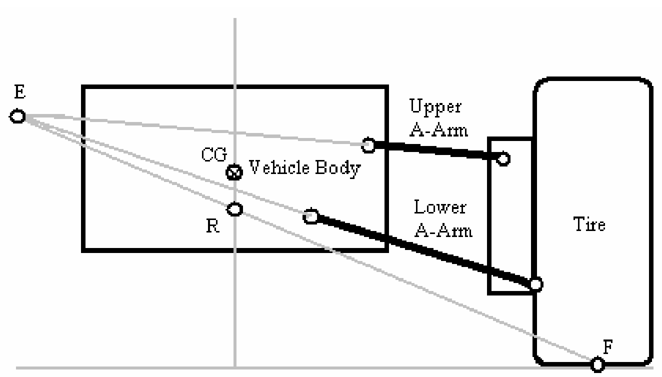

Figure 41 - Vehicle Roll Center

The 4.7 inch difference in height of the center of gravity between the two test vehicles affects their behavior in the lane change and slalom tests. The roll center is the axis about which rolling motion occurs. It is determined by the vehicle's geometry; in the HMMWV it is 15.6 inches high.

Lateral forces applied at the center of gravity are multiplied by the distance between the center of gravity and the roll center to produce torques about the roll center. The moment arm is 12.8 inches for the M1037 HMMWV and 17.5 inches for the M1025 HMMWV. The ratio of 17.5 / 12.8 equals 1.37. This means that the same lateral acceleration (produced by turning) will result in 37% more torque about the roll axis in the M1025 than in the M1037.

The total lateral acceleration measured at the center of gravity is the sum of the centripetal acceleration and the acceleration about the roll axis as described above. The main factors in rolling acceleration are the torsional stiffness of the suspension and the length of the moment arm. Suspension stiffness is one of the properties being tested, but the moment arm (CG height – roll center) should be the same between the two test vehicles for an accurate comparison.

RESULTS AND OBSERVATIONS

The ride quality performance of the HMMWV with the low bandwidth active CF suspension was quite impressive. This was despite the fact that the control system seemed to be more of a height management system than a system designed to improve vehicle ride quality. The small fluid accumulator and the fairly low pressure differential would also seem to restrict the command authority of the strut/actuator. It is anticipated that future efforts in these areas might further increase the ride quality performance of this system.

The performance of the CF suspension in the lane change maneuvers was lower than that of the passive HMMWV. As noted earlier, this is probably at least partially due to different cg heights and the removal of the anti-roll bar from the CF HMMWV. It is also anticipated that additional actuator authority and control system enhancements could reverse this performance difference.

ACKNOWLEDGEMENTS

The authors would like to thank all of those involved, especially Instrumentation, Data Collection, Video, and the Drivers from YPG

CONTACT

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Lins, W.F., "Human Vibration Response Measurement", TR 11551, U.S. Army Tank Automotive Command, Warren, MI, 1972.
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Pradko, F., Lee, R., Kaluza, V.,"Theory of Human Vibration Response", ASME Paper No. 66-WA/BHF-15, 1966.
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DEFINITIONS, ACRONYMS, ABBREVIATIONS

cg - Center of Gravity
CFS – Compressible Fluid Suspension
CRADA – Cooperative Research and Development Agreement
EMS – Electromechanical Suspension
HMMWV - High Mobility Multi-purpose Wheeled Vehicle
MPH - Mile per hour
rms - Root Mean Square
TACOM - U.S. Army Tank-automotive and Armaments Command
TARDEC U.S. Army Tank-Automotive Research, Development and Engineering Center
YPG - Yuma Proving Grounds

APPENDIX A - Scope of Work

Scope of Work

1 SCOPE. This Scope of Work (SOW) covers technical support and testing services to be provided to the Mobility Directorate of the U.S. Army Tank-automotive and Armaments Command (TACOM). This support encompasses technical work and the use of test facilities.

1.1 Background. TACOM is involved in the development of advanced suspension technology to increase the mobility performance of Army vehicles. The particular application of a compressible fluid suspension (CFS) to achieve increased performance is being explored. Comparison testing between the compressible fluid suspension and a passive system is being sought to quantify the actual performance gains for ride quality, shock, and maneuverability. The platform for this particular test is the High Mobility Multi-purpose Wheeled Vehicle (HMMWV). One test period of one to two weeks is planned for running both the compressible fluid suspension vehicle and the passive HMMWV.

2 APPLICABLE DOCUMENTS.

2.1 Course Layouts. See Appendix A1.

2.2 Testing Procedures. See Appendix A2.

3 REQUIREMENTS.

3.1 General. Use of the test facilities shall include support of test personnel, preparation of test areas or courses in conjunction with tests requested, installation of data collection equipment and instrumentation, and production of test results in digital form on CD-ROM or Zip disk format and video requested. TACOM will coordinate the overall test program with cooperation from Davis Technologies. YPG shall arrange delivery of the CFS HMMWV. Testing shall begin upon the arrival of the CFS HMMWV. All test results shall be delivered no later than 30 days after final testing is completed.

3.2 Instrumentation. The passive HMMWV and CFS HMMWV vehicles shall be instrumented with sensors mounted on solid non-resonating surfaces to measure the following at the specified location:

3.2.1.1 A tri-axle hub accelerometer on a front wheel of both the test vehicle and the passive vehicle that is capable of measuring 100g. (1 sensor)

3.2.1.2 Differential position of suspension or wheel travel for each wheel (4 sensors)

3.2.1.3 Tri-axial acceleration at CG (vertical, longitudinal, lateral) (1 sensor)

3.2.1.4 Tri-axial angular rate at CG (roll, pitch, yaw) (1 sensor)

3.2.1.5 Speed (longitudinal) (1 sensor)

3.2.1.6 Steering angle (1 sensor)

3.2.1.7 Vertical acceleration at driver's floor (1 sensor)

3.2.2 An Instrumentation Map shall be provided for each test conducted.

3.3 Test Descriptions.

3.3.1 Ride. Ride quality tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the following courses (approx. RMS) starting at 5 MPH in 5-MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.1a Rolling Resistance. The Rolling Resistance or "Coast Down" test should be conducted according to the test procedure described in the Appendix (A2). Tests should be conducted on level, Course 3 (1.5" RMS), and Course 4 (2.0" RMS) from a range starting at 5 MPH and ending at 25 MPH.:

3.3.1.1 Course 3 - 1.5" RMS roughness

3.3.1.2 Course 4 - 2.0" RMS roughness

3.3.1.3 Course 5 - 3.4" RMS roughness

3.3.2 Shock. Shock level tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the following, full vehicle width, half-round bump heights starting at 5 MPH in 5-MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.2.0 4" half-round

3.3.2.1 6" half-round

3.3.2.2 8" half-round

3.3.3 Maneuverability.

3.3.3.1 Double Lane Change. Double Lane Change tests shall be conducted according to the test procedure described in the Appendix (A2). (For the case of the HMMWV the vehicle length and width shall be 15 ft and 7 ft, respectively). Each vehicle shall be driven over the course starting at 5 MPH in 5-MPH increments (refinement to 2.5 MPH increments may be needed for special cases).

3.3.3.2 Constant Step Slalom. Constant Step Slalom tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the course with the following cone spacing starting at 5 MPH in 5-MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.3.2.1 d = 30 m (98.4 ft)

3.4 Data Acquisition. All tests shall be run at the specified constant speeds or until deemed unsafe. A check of test data shall be made after each run and if any channel failure or dropout is present that test shall be rerun in entirety. The sample rate will be conducted at 500 Hz except for the shock test. The shock level half-round test shall be conducted at a frequency of at least 1000 Hz. All data taken from the hub accelerometer is to be taken unfiltered. All channel data for each test shall be stored and delivered on CD-ROM or Zip Disk format media in ASCII format (including file content description). Side and frontal video shots shall be taken of each test. A digital profile of all ride courses used shall be provided.

APPENDIX

A1 COURSE LAYOUTS

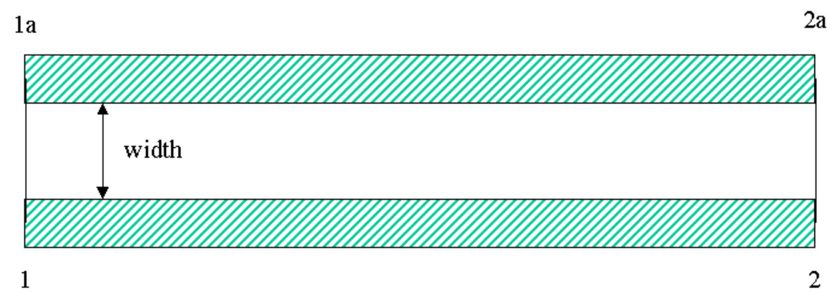

Figure A1 - Ride Course Layout

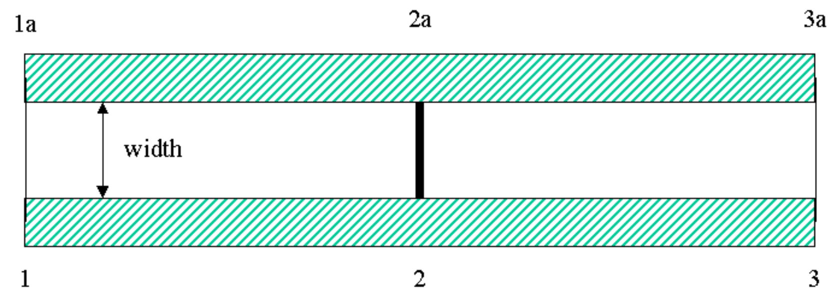

Figure A2 - Bump Course Layout

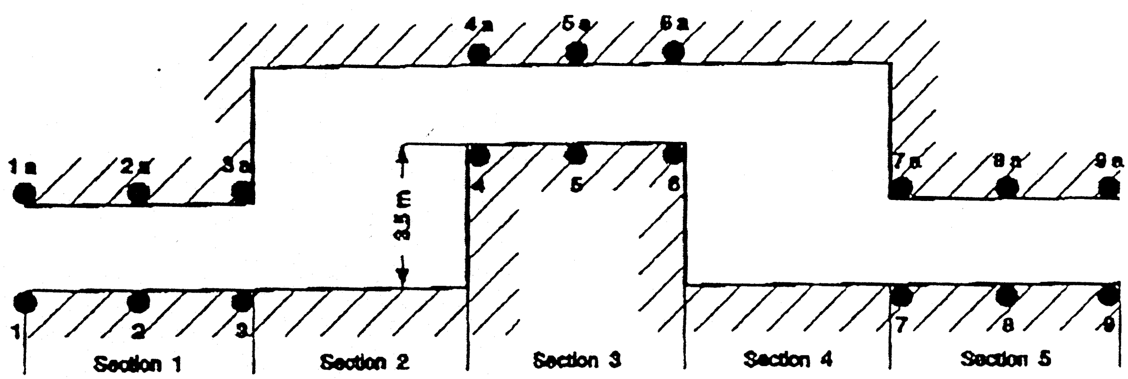

Figure A3 - Lane Change Layout

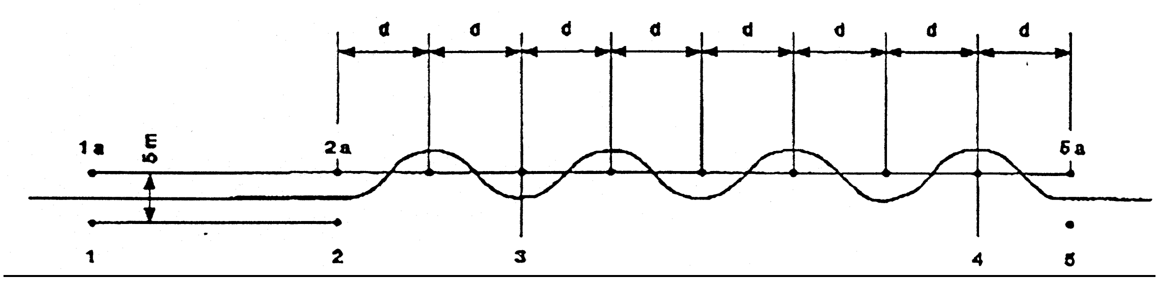

Figure A4 - Constant Step Slalom Layout

A2 TEST PROCEDURES

A2.1 Ride.

A2.1.a Set up the course shown (Figure A1) with width at least two times the vehicle width and with distance (1-2) at least 150 m (492 ft).

A2.1.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-2); attempt to continue through the remainder of the course whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A2.1.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without staying on the course or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A2.1.d Repeat the above procedure (a) to (c), but with the courses roughness as laid down in the test plan.

A2.2 Shock.

A2.2.a Set up the course shown (Figure A2) with width at least two times the vehicle width including a full vehicle width half-round bump at (2-2a).

A2.2.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-3); attempt to continue through the remainder of the course whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A2.2.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without staying on the course or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A2.2.d Repeat the above procedure (a) to (c), but with the half-round bump height as laid down in the test plan.

A3.3 Maneuverability.

A3.3.1 Double Lane Change.

A3.3.1.a Set up the course shown (Figure A3) with the following dimensions:

Section 1:Length = 15 m (49.2 ft)
Width = 1.1 * vehicle width + 0.25 m (0.82 ft)

Section 2:Length = vehicle length + 24 m (78.72 ft)
Width = 3.5 m (11.48 ft) + Section 3 width
Section 3 Length = 25 m (82 ft)
Width = 1.2 * vehicle width + 0.25m (0.82 ft)

Section 4:Length = vehicle length + 24 m (78.72 ft)
Width = 3.5 m (11.48 ft) + Section 3 width

Section 5:Length = 15 m (49.2 ft)
Width = 1.1 * vehicle width + 0.25 m (0.82 ft)

A3.3.1.b Cross the line (1-1a) with the lowest vehicle speed laid down in test plan and drive in a straight line through the first section (1-3); attempt to continue through the remainder of the course (3-9) whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A3.3.1.c Repeat (b) at the various speed increments laid down in the test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without knocking the cones down or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A3.3.2 Constant Step Slalom.

A3.3.2.a Set up the course shown (Figure A4) with distance "d" as laid out in the test plan and with distances (1-1a, 2-2a, 5-5a) at 5 m (16.4 ft).

A3.3.2.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-2); attempt to continue through the remainder of the course (2-5)) whilst keeping the speed as steady as possible at this same value. The time needed to cross the section (3-4) is to be measured. Record parameters and note the vehicle behavior during the test.

A3.3.2.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without knocking the cones down or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A3.3.2.d Repeat the above procedure (a) to (c), but with the distances "d" set in turn at 15, 20 and 30 m (49.2, 65.6, and 98.4 ft).

APPENDIX B - Test Matrix

COMPRESSIBLE FLUID SUSPENSION
23 September 2002

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver	
Active 23 Sep 02.000	1	N	30	Straight	Active	Curtis	
Active 23 Sep 02.001	2	S	35	Straight	Active	Curtis	
Active 23 Sep 02.002	3	N	40	Straight	Active	Ken	
Active 23 Sep 02.003	4	S	45	Straight	Active	Ken	
Active 23 Sep 02.004	5	N	50	Straight	Active	Curtis	
Active 23 Sep 02.005	6	S	55	Straight	Active	Curtis	
Passive 23 Sep 02.000	1	N	30	Straight	Passive	Curtis	
Passive 23 Sep 02.001	2	S	35	Straight	Passive	Curtis	
Passive 23 Sep 02.002	3	N	40	Straight	Passive	Ken	
Passive 23 Sep 02.003	4	S	45	Straight	Passive	Ken	
Passive 23 Sep 02.004	5	N	50	Straight	Passive	Curtis	
Passive 23 Sep 02.005	6	S	55	Straight	Passive	Curtis	
Active 23 Sep 02.006	1	N	10	Slalom	Active	Ken	
Active 23 Sep 02.007	2	S	15	Slalom	Active	Ken	
Active 23 Sep 02.008	3	S	20	Slalom	Active	Curtis	
Active 23 Sep 02.009	4	N	25	Slalom	Active	Curtis	
Active 23 Sep 02.010	5	N	20	Slalom	Active	Ken	Active Suspension Disabled
Active 23 Sep 02.011	6	S	25	Slalom	Active	Ken	Active Suspension Disabled
Active 23 Sep 02.012	7	N	30	Slalom	Active	Ken	
Active 23 Sep 02.013	8	S	35	Slalom	Active	Ken	
Active 23 Sep 02.014	9	N	40	Slalom	Active	Curtis	
Active 23 Sep 02.015	10	S	45	Slalom	Active	Curtis	
Active 23 Sep 02.016	11	N	45	Slalom	Active	Ken	
Passive 23 Sep 02.006	1	N	10	Slalom	Passive	Ken	
Passive 23 Sep 02.007	2	S	15	Slalom	Passive	Ken	
Passive 23 Sep 02.008	3	S	20	Slalom	Passive	Curtis	
Passive 23 Sep 02.009	4	N	25	Slalom	Passive	Curtis	
Passive 23 Sep 02.010	5	N	30	Slalom	Passive	Ken	
Passive 23 Sep 02.011	6	S	35	Slalom	Passive	Ken	
Passive 23 Sep 02.012	7	N	40	Slalom	Passive	Curtis	

COMPRESSIBLE FLUID SUSPENSION
24 September 2002

*Note - Found a problem with CG - Z Axis channel upon completion of testing
It was clipping data above 1.5 g's. Replaced with another accelerometer for sept 26 on

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver	
Active 24 Sep 02.000	1	N	10	Lane Change	Active	Ken	
Active 24 Sep 02.001	2	S	15	Lane Change	Active	Ken	
Active 24 Sep 02.002	3	N	20	Lane Change	Active	Ken	
Active 24 Sep 02.003	4	S	25	Lane Change	Active	Ken	
Active 24 Sep 02.004	5	N	30	Lane Change	Active	Ken	
Active 24 Sep 02.005	6	S	35	Lane Change	Active	Ken	
Active 24 Sep 02.006	7	N	40	Lane Change	Active	Ken	
Active 24 Sep 02.007	8	S	45	Lane Change	Active	Ken	
Active 24 Sep 02.008	9	N	45	Lane Change	Active	Ken	
Active 24 Sep 02.009	10	S	47.5	Lane Change	Active	Ken	
Active 24 Sep 02.010	11	S	47.5	Lane Change	Active	Ken	
Active 24 Sep 02.011	1	S	5	RMS 3	Active	Curtis	right rear displacement
Active 24 Sep 02.012	2	N	5	RMS 3	Active	Curtis	bad for runs 1-6
Active 24 Sep 02.013	3	S	10	RMS 3	Active	Curtis	
Active 24 Sep 02.014	4	N	10	RMS 3	Active	Curtis	
Active 24 Sep 02.015	5	S	15	RMS 3	Active	Curtis	
Active 24 Sep 02.016	6	N	15	RMS 3	Active	Curtis	
Active 24 Sep 02.017	7	S	10	RMS 3	Active	Curtis	
Active 24 Sep 02.018	8	N	15	RMS 3	Active	Curtis	
Active 24 Sep 02.019	9	S	20	RMS 3	Active	Curtis	
Active 24 Sep 02.020	10	N	20	RMS 3	Active	Curtis	
Active 24 Sep 02.021	11	S	25	RMS 3	Active	Curtis	
Active 24 Sep 02.022	12	N	25	RMS 3	Active	Curtis	
Active 24 Sep 02.023	13	S	30	RMS 3	Active	Curtis	
Active 24 Sep 02.024	14	N	30	RMS 3	Active	Curtis	
Active 24 Sep 02.025	15	S	35	RMS 3	Active	Curtis	
Active 24 Sep 02.026	16	N	35	RMS 3	Active	Curtis	
Active 24 Sep 02.027	17	S	40	RMS 3	Active	Curtis	
Active 24 Sep 02.028	18	N	40	RMS 3	Active	Curtis	
Active 24 Sep 02.029	19	S	45	RMS 3	Active	Curtis	

COMPRESSIBLE FLUID SUSPENSION
24 September 2002

*Note - Found a problem with CG - Z Axis channel upon completion of testing
It was clipping data above 1.5 g's. Replaced with another accelerometer for sept 26 on

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver	
Passive 24 Sep 02.000	1	N	10	Lane Change	Passive	Ken	
Passive 24 Sep 02.001	2	S	15	Lane Change	Passive	Ken	
Passive 24 Sep 02.002	3	N	20	Lane Change	Passive	Ken	
Passive 24 Sep 02.003	4	S	25	Lane Change	Passive	Ken	
Passive 24 Sep 02.004	5	N	30	Lane Change	Passive	Ken	
Passive 24 Sep 02.005	6	S	35	Lane Change	Passive	Ken	
Passive 24 Sep 02.006	7	N	40	Lane Change	Passive	Ken	
Passive 24 Sep 02.007	8	S	45	Lane Change	Passive	Ken	
Passive 24 Sep 02.008	9	N	47.5	Lane Change	Passive	Ken	
Passive 24 Sep 02.009	10	S	50	Lane Change	Passive	Ken	
Passive 24 Sep 02.010	1	S	10	RMS 3	Passive	Curtis	
Passive 24 Sep 02.011	2	N	10	RMS 3	Passive	Curtis	
Passive 24 Sep 02.012	3	S	15	RMS 3	Passive	Curtis	
Passive 24 Sep 02.013	4	N	15	RMS 3	Passive	Curtis	
Passive 24 Sep 02.014	5	S	20	RMS 3	Passive	Curtis	
Passive 24 Sep 02.015	6	N	20	RMS 3	Passive	Curtis	
Passive 24 Sep 02.016	7	S	25	RMS 3	Passive	Curtis	
Passive 24 Sep 02.017	8	N	25	RMS 3	Passive	Curtis	
Passive 24 Sep 02.018	9	S	30	RMS 3	Passive	Curtis	
Passive 24 Sep 02.019	10	N	30	RMS 3	Passive	Curtis	Possible Extra File
Passive 24 Sep 02.020	11	S	35	RMS 3	Passive	Curtis	Aborted Run

COMPRESSIBLE FLUID SUSPENSION

CG - Z Axis accelerometer replaced prior to beginning of testing

26 September 2002

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver	
Active 26 Sep 02.000	1	N	10	RMS 4	Active	Ken	
Active 26 Sep 02.001	2	S	10	RMS 4	Active	Ken	
Active 26 Sep 02.002	3	N	15	RMS 4	Active	Ken	
Active 26 Sep 02.003	4	S	15	RMS 4	Active	Ken	
Active 26 Sep 02.004	5	S	20	RMS 4	Active	Ken	
Active 26 Sep 02.005	6	N	20	RMS 4	Active	Ken	
Active 26 Sep 02.006	7	S	25	RMS 4	Active	Ken	
Active 26 Sep 02.007	8	N	25	RMS 4	Active	Ken	
Active 26 Sep 02.008	9	S	30	RMS 4	Active	Ken	
Active 26 Sep 02.009	1	S	10	RMS 5	Active	Curtis	
Active 26 Sep 02.010	2	N	10	RMS 5	Active	Curtis	
Active 26 Sep 02.011	3	S	12.5	RMS 5	Active	Curtis	
Active 26 Sep 02.012	4	S	12.5	RMS 5	Active	Curtis	
Active 26 Sep 02.013	1	N	15	RMS 4 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.014	2	N	20	RMS 4 - Rolling Resistance	Active	Curtis	System turned off sometime during run
Active 26 Sep 02.015	2A	N	20	RMS 4 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.016	3	N	25	RMS 4 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.017	1	N	15	RMS 3 - Rolling Resistance	Active	Ken	
Active 26 Sep 02.018	2	N	20	RMS 3 - Rolling Resistance	Active	Ken	
Active 26 Sep 02.019	3	N	25	RMS 3 - Rolling Resistance	Active	Ken	
Active 26 Sep 02.020	1	N	15	Old95 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.021	1A	N	15	Old95 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.022	2	N	20	Old95 - Rolling Resistance	Active	Curtis	
Active 26 Sep 02.023	3	N	25	Old95 - Rolling Resistance	Active	Curtis	

COMPRESSIBLE FLUID SUSPENSION
26 September 2002

CG - Z Axis accelerometer replaced prior to beginning of testing

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver	
Passive 26 Sep 02.000	1	N	10	RMS 4	Passive	Ken	
Passive 26 Sep 02.001	2	S	10	RMS 4	Passive	Ken	
Passive 26 Sep 02.002	3	N	15	RMS 4	Passive	Ken	
Passive 26 Sep 02.003	4	S	15	RMS 4	Passive	Ken	
Passive 26 Sep 02.004	5	S	20	RMS 4	Passive	Ken	
Passive 26 Sep 02.005	6	N	20	RMS 4	Passive	Ken	
Passive 26 Sep 02.006	7	S	25	RMS 4	Passive	Ken	
Passive 26 Sep 02.007	8	N	25	RMS 4	Passive	Ken	
Passive 26 Sep 02.008	1	S	10	RMS 5	Passive	Curtis	
Passive 26 Sep 02.009	1	N	15	RMS 4 - Rolling Resistance	Passive	Curtis	
Passive 26 Sep 02.010	2	N	20	RMS 4 - Rolling Resistance	Passive	Curtis	
Passive 26 Sep 02.011	2A	N	20	RMS 4 - Rolling Resistance	Passive	Curtis	
Passive 26 Sep 02.012	2B	N	20	RMS 4 - Rolling Resistance	Passive	Curtis	Bad Run
Passive 26 Sep 02.013	3	N	25	RMS 4 - Rolling Resistance	Passive	Curtis	Bad Run
Passive 26 Sep 02.014	1	N	15	RMS 3 - Rolling Resistance	Passive	Ken	
Passive 26 Sep 02.015	2	N	20	RMS 3 - Rolling Resistance	Passive	Ken	
Passive 26 Sep 02.016	3	N	25	RMS 3 - Rolling Resistance	Passive	Ken	
Passive 26 Sep 02.017	3A	N	25	RMS 3 - Rolling Resistance	Passive	Ken	
							Bad Run
Passive 26 Sep 02.018	1	N	15	Old95 - Rolling Resistance	Passive	Ken	
Passive 26 Sep 02.019	2	N	20	Old95 - Rolling Resistance	Passive	Ken	
Passive 26 Sep 02.020	3	N	25	Old95 - Rolling Resistance	Passive	Ken	

COMPRESSIBLE FLUID SUSPENSION

27 September 2002

2 dataloggers were used. Logger A contains all channels but the 4 displacement channels.

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver
Active 27 Sep 02.000	1	S	2	4" Bump	Active	Curtis
Active 27 Sep 02.001	2	S	5	4" Bump	Active	Curtis
Active 27 Sep 02.002	3	S	7	4" Bump	Active	Curtis
Active 27 Sep 02.003	4	S	10	4" Bump	Active	Curtis
Active 27 Sep 02.004	4A	S	10	4" Bump	Active	Curtis
Active 27 Sep 02.005	5	S	13	4" Bump	Active	Curtis
Active 27 Sep 02.006	6	S	15	4" Bump	Active	Curtis
Active 27 Sep 02.007	7	S	20	4" Bump	Active	Curtis
Active 27 Sep 02.008	8	S	20	4" Bump	Active	Curtis
Active 27 Sep 02.009	9	S	18	4" Bump	Active	Curtis
Active 27 Sep 02.010	1	S	2	6" Bump	Active	Ken
Active 27 Sep 02.011	2	S	5	6" Bump	Active	Ken
Active 27 Sep 02.012	3	S	7	6" Bump	Active	Ken
Active 27 Sep 02.013	4	S	10	6" Bump	Active	Ken
Active 27 Sep 02.014	5	S	13	6" Bump	Active	Ken
Active 27 Sep 02.015	6	S	15	6" Bump	Active	Ken
Active 27 Sep 02.016	7	S	18	6" Bump	Active	Ken
Active 27 Sep 02.017	8	S	20	6" Bump	Active	Ken
Active 27 Sep 02.018	1	S	3	8" Bump	Active	Curtis
Active 27 Sep 02.019	2	S	4	8" Bump	Active	Curtis
Active 27 Sep 02.020	3	S	5	8" Bump	Active	Curtis
Active 27 Sep 02.021	4	S	7	8" Bump	Active	Curtis
Active 27 Sep 02.022	5	S	8	8" Bump	Active	Curtis
Active 27 Sep 02.023	6	S	10	8" Bump	Active	Curtis

COMPRESSIBLE FLUID SUSPENSION

27 September 2002

2 dataloggers were used. Logger A contains all channels but the 4 displacement channels.

Filename	Run	Direction	Speed	Scenario	Vehicle	Driver
Passive 27 Sep 02.000	1	S	2	4" Bump	Passive	Curtis
Passive 27 Sep 02.001	2	S	5	4" Bump	Passive	Curtis
Passive 27 Sep 02.002	3	S	8	4" Bump	Passive	Curtis
Passive 27 Sep 02.003	4	S	10	4" Bump	Passive	Curtis
Passive 27 Sep 02.004	5	S	13	4" Bump	Passive	Curtis
Passive 27 Sep 02.005	6	S	15	4" Bump	Passive	Curtis
Passive 27 Sep 02.006	7	S	18	4" Bump	Passive	Curtis
Passive 27 Sep 02.007	8	S	20	4" Bump	Passive	Curtis
Passive 27 Sep 02.008	1	S	2	6" Bump	Passive	Ken
Passive 27 Sep 02.009	2	S	5	6" Bump	Passive	Ken
Passive 27 Sep 02.010	3	S	7	6" Bump	Passive	Ken
Passive 27 Sep 02.011	4	S	10	6" Bump	Passive	Ken
Passive 27 Sep 02.012	5	S	13	6" Bump	Passive	Ken
Passive 27 Sep 02.013	6	S	15	6" Bump	Passive	Ken
Passive 27 Sep 02.014	7	S	18	6" Bump	Passive	Ken
No Data	1	S	2	8" Bump	Passive	Curtis
Passive 27 Sep 02.015	2	S	4	8" Bump	Passive	Curtis
Passive 27 Sep 02.016	3	S	5	8" Bump	Passive	Curtis
Passive 27 Sep 02.017	4	S	6	8" Bump	Passive	Curtis
Passive 27 Sep 02.018	5	S	8	8" Bump	Passive	Curtis
Passive 27 Sep 02.019	6	S	10	8" Bump	Passive	Curtis

APPENDIX C - Passive and Test HMMWV Sensor Instrumentation List

Passive and Test HMMWV Sensor List

Revised 11-14-02

Channel #	Sensor	Location	Type	Elements	Direction	Scale Factor	Coordinates (in)	Comments
1	Wheel Acceleration RF-X axis “Gs”	Right Front Hub	Capacitance Accelerometer	1	Forward = Positive	.		Endevco 7290A--100, ± 100g,
2	Wheel Acceleration RF-Y axis “Gs”	Right Front Hub	Capacitance Accelerometer	1	Left = Positive	.		Endevco 7290A-100, ± 100g,
3	Wheel Acceleration RF-Z axis “Gs”	Right Front Hub	Capacitance Accelerometer	1	Up = Positive	.		Endevco 7290A-100, ± 100g,
4	CG Longitudinal Acceleration X axis “Gs”	Cargo area sheetmetal between seats	Capacitance Accelerometer	1	Forward = Positive	.		Endevco 7290A-30, ± 30g, 0-800 Hz
5	CG Lateral Acceleration Y axis “Gs”	Cargo area sheetmetal between seats	Capacitance Accelerometer	1	Left = Positive	.		Endevco 7290A-30, ± 30g, 0-800 Hz
6	CG Vertical Acceleration Z axis “Gs”	Cargo area sheetmetal between seats	Capacitance Accelerometer	1	Up = Positive	.		Endevco 7290A-30 ± 30g, 0-800 Hz
7	Driver’s Vertical Acceleration “Gs”	Frame crossmember behind seat	Capacitance Accelerometer	1	Up = Positive	.		Endevco 7290A-10 ± 10g

8	Pitch “Deg/sec”	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Nose Down= Positive	.		
9	Roll “Deg/sec”	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Roll Left= Positive	.		
10	Yaw “Deg/sec”	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Nose Right= Positive	.		
Channel #	**Sensor**	**Location**	**Type**	**Elements**	**Direction**	**Scale Factor**	**Coordinates (in)**	**Comments**
11	Road Speed “MPH”	LR Wheel	Di-mag Pulse Counter	1	N/A			
12	Steering Angle “Degrees”	Frame crossmember behind seat	Linear Position Transducer	1	Right turn =Positive		Steering Gear Box Pitman Arm	Space Age Controls Inc. 160-1705 Position Transducer
13	Wheel Displacement LF “Inches”	Left Front Upper A-arm Ball Joint	Linear Position Transducer	1	Extension =Positive			UniMeasure PA-30-NJC 30 in
14	Wheel Displacement LR “Inches”	Left Rear Upper A-arm Ball Joint	Linear Position Transducer	1	Extension =Positive			UniMeasure PA-30-NJC 30 in
15	Wheel Displacement RF “Inches”	Right Front Upper A-arm Ball Joint	Linear Position Transducer	1	Extension =Positive			UniMeasure PA-30-NJC 30 in
16	Wheel Displacement RR “Inches”	Right Rear Upper A-arm Ball Joint	Linear Position Transducer	1	Extension = Positive			UniMeasure PA-30-NJC 30 in.

APPENDIX D - Passive and Test HMMWV Minimum and Maximum Values

Test HMMWV RMS Maximum and Minimum

TEST	24011	24012	24013	24014	24015	24016	24017	24018	24019	24020
frntx =	0.41	0.55	1.08	1.17	1.16	1.30	1.08	2.17	2.07	3.00
frntxn =	-0.47	-0.43	-1.14	-1.25	-2.01	-1.72	-0.98	-2.03	-2.86	-4.69
frnty =	0.60	0.46	0.93	0.91	1.75	1.53	1.09	2.86	2.95	5.11
frntyn =	-0.69	-0.52	-2.75	-1.88	-4.15	-4.08	-1.55	-6.46	-5.33	-12.66
frntz =	1.78	1.01	1.75	1.86	4.10	3.59	1.80	5.76	5.11	10.65
frntzn =	-1.63	-1.12	-1.91	-1.68	-3.16	-3.28	-2.24	-3.92	-6.52	-6.12
cgx =	0.16	0.21	0.27	0.31	0.29	0.42	0.24	0.37	0.44	0.64
cgxn =	-0.16	-0.14	-0.30	-0.32	-0.28	-0.27	-0.25	-0.66	-0.49	-0.80
cgy =	0.14	0.20	0.28	0.31	0.30	0.30	0.22	0.45	0.57	0.89
cgyn =	-0.16	-0.15	-0.28	-0.26	-0.24	-0.32	-0.25	-0.81	-0.40	-0.73
cgz =	0.35	0.39	1.34	1.12	0.70	0.92	1.08	1.12	1.36	1.41
cgzn =	-0.36	-0.37	-1.22	-0.92	-0.76	-0.90	-0.98	-1.67	-1.18	-1.86
drvr =	0.34	0.31	1.36	1.20	0.80	0.83	1.00	1.43	1.62	3.07
drvrn =	-0.32	-0.29	-1.21	-1.04	-0.83	-1.60	-0.98	-1.78	-1.32	-1.67
ptch =	8.05	12.58	23.61	24.44	27.30	32.42	26.70	37.70	42.42	44.26
ptchn =	-12.01	-11.87	-25.00	-25.93	-29.21	-30.31	-27.10	-38.86	-41.50	-51.86
roll =	7.28	11.63	12.29	14.07	8.37	9.85	9.15	38.74	15.32	17.23
rolln =	-8.91	-8.68	-14.14	-16.17	-9.67	-9.27	-11.25	-16.92	-15.70	-19.41
yaw =	2.60	2.30	3.57	4.03	3.79	3.73	3.57	38.56	3.93	5.52
yawn =	-2.53	-1.72	-5.01	-3.50	-4.19	-4.60	-3.00	-11.07	-6.29	-7.34
ster =	1.81	1.25	0.73	1.52	0.95	1.11	1.25	1.34	1.20	1.43
stern =	-2.10	-1.59	-1.50	-2.42	-2.30	-1.71	-1.42	-43.94	-3.03	-3.21
lfrt =	1.05	1.27	4.31	4.24	4.23	4.40	4.26	4.59	4.54	4.63
lfrtn =	-0.99	-0.78	-3.23	-3.50	-3.53	-3.56	-2.88	-4.31	-3.79	-4.00
lrr =	0.83	0.71	4.56	3.12	2.26	2.85	3.55	4.01	4.29	4.71
lrrn =	-1.22	-1.17	-3.89	-3.87	-2.79	-2.74	-3.73	-7.63	-3.48	-3.72
rfrt =	1.45	2.13	4.42	4.52	4.48	4.51	4.28	4.67	4.60	4.76
rfrtn =	-0.75	-1.11	-2.73	-2.46	-2.67	-3.02	-2.58	-3.62	-2.84	-3.62
rrr =	~~0.01~~	~~0.01~~	~~2.29~~	~~2.30~~	~~2.29~~	~~2.29~~	3.83	4.26	3.62	4.64
rrrn =	~~0.00~~	~~0.00~~	~~0.55~~	~~2.28~~	~~2.28~~	~~2.28~~	-3.60	-9.33	-3.02	-2.99
spd =	5.30	5.29	10.05	10.37	15.51	15.17	10.77	14.86	20.44	20.42
runtime =	131.00	111.49	69.73	69.01	46.16	47.61	66.23	46.99	34.63	35.37

Test HMMWV RMS Maximum and Minimum continued

TEST	24021	24022	24023	24024	24025	24026	24027	24028	24029	26000	26001
frntx =	2.09	3.08	2.39	3.81	3.44	3.54	4.78	6.10	6.26	1.70	1.12
frntxn =	-2.21	-3.96	-3.63	-3.22	-4.04	-5.41	-4.51	-6.50	-6.56	-1.37	-1.35
frnty =	2.62	4.81	3.54	4.95	4.67	6.26	8.18	8.09	9.58	1.48	1.46
frntyn =	-7.75	-13.82	-9.74	-11.79	-10.99	-13.48	-12.14	-14.75	-15.12	-2.52	-2.66
frntz =	6.71	11.43	8.66	11.74	11.49	13.65	15.32	14.33	16.48	3.26	2.57
frntzn =	-7.29	-7.69	-9.53	-11.36	-12.39	-12.16	-16.29	-13.23	-18.41	-2.31	-2.61
cgx =	0.43	1.06	0.52	1.76	0.57	1.82	1.24	2.31	1.82	0.36	0.35
cgxn =	-0.41	-1.11	-0.69	-0.85	-0.95	-1.05	-1.10	-1.43	-1.47	-0.49	-0.43
cgy =	0.64	1.23	0.67	1.62	0.95	1.86	1.46	1.94	1.76	0.29	0.29
cgyn =	-0.47	-0.98	-0.78	-1.21	-1.09	-1.76	-1.79	-1.74	-1.84	-0.29	-0.29
cgz =	0.95	1.37	1.37	1.37	1.39	1.40	1.41	1.50	1.44	0.97	0.94
cgzn =	-1.37	-1.83	-1.86	-2.59	-1.93	-2.79	-2.14	-2.96	-2.94	-0.97	-1.21
drvr =	1.06	1.97	1.57	1.68	1.56	1.81	2.71	6.19	3.68	0.97	1.01
drvrn =	-1.52	-1.64	-2.63	-2.00	-4.91	-1.74	-2.07	-2.61	-5.09	-1.04	-1.19
ptch =	41.46	42.54	50.54	40.18	37.20	44.71	42.85	56.16	50.10	28.75	-4.92
ptchn =	-42.98	-50.42	-38.77	-41.44	-41.94	-36.09	-41.00	-45.73	-39.35	-28.08	-5.76
roll =	13.79	17.97	14.44	16.02	14.93	19.76	18.32	33.92	23.06	12.82	9.30
rolln =	-12.27	-15.04	-10.65	-17.35	-12.18	-15.42	-14.12	-19.60	-20.80	-12.08	-10.91
yaw =	5.51	5.73	5.53	6.19	5.10	6.55	8.44	7.53	9.00	2.44	2.80
yawn =	-2.95	-4.36	-3.67	-5.14	-7.14	-6.26	-6.90	-7.58	-10.12	-2.78	-3.65
ster =	0.88	2.02	1.06	1.36	1.57	2.14	2.17	1.68	1.91	1.45	1.34
stern =	-1.69	-2.52	-2.18	-2.37	-3.06	-2.17	-3.32	-2.29	-3.47	-0.57	-0.78
lfrt =	4.50	4.62	4.54	4.64	4.56	4.66	4.58	4.65	4.62	4.22	4.26
lfrtn =	-3.25	-4.08	-3.04	-3.99	-3.09	-4.14	-3.08	-3.05	-3.09	-2.58	-3.07
lrr =	4.13	5.02	3.86	5.06	4.83	5.06	4.96	5.12	5.09	4.07	4.76
lrrn =	-3.87	-4.06	-4.13	-4.14	-4.24	-4.31	-4.43	-4.45	-4.48	-3.72	-3.64
rfrt =	4.61	4.74	4.62	4.73	4.63	4.76	4.68	4.71	4.78	4.33	4.31
rfrtn =	-3.29	-3.43	-3.28	-3.55	-3.18	-3.60	-3.61	-2.98	-3.94	-2.66	-2.73
rrr =	3.89	5.20	4.47	5.27	5.02	5.31	5.21	5.32	5.37	4.32	5.11
rrrn =	-3.73	-3.93	-3.94	-4.11	-4.06	-4.15	-4.46	-4.56	-4.52	-3.79	-3.75
spd =	25.09	25.04	30.45	30.96	35.05	34.78	40.61	40.82	45.11	11.29	11.93
runtime =	28.54	29.02	26.06	25.11	21.82	24.12	22.16	18.01	18.07	61.17	57.31

Test HMMWV RMS Maximum and Minimum continued

TEST	26002	26003	26004	26005	26006	26007	26008	26009	26010	26011	26012
frntx =	3.45	2.25	2.28	2.79	3.21	3.83	4.52	3.44	4.01	8.32	8.37
frntxn =	-4.17	-3.76	-3.08	-4.31	-4.54	-6.21	-6.66	-6.95	-5.06	-10.52	-10.60
frnty =	4.51	3.97	3.23	5.34	5.43	7.10	6.74	8.12	5.24	9.42	11.20
frntyn =	-6.56	-8.75	-9.61	-9.35	-11.75	-11.58	-14.12	-7.66	-6.85	-9.90	-10.59
frntz =	7.25	6.49	6.91	8.52	9.22	9.83	11.86	11.50	8.96	14.99	16.55
frntzn =	-6.18	-4.80	-4.24	-5.55	-5.92	-8.44	-8.58	-6.98	-5.76	-11.52	-14.84
cgx =	0.61	1.09	0.86	0.90	1.73	1.93	2.48	1.09	1.09	0.87	1.11
cgxn =	-0.76	-0.83	-0.83	-1.07	-2.06	-1.69	-2.22	-1.06	-1.04	-2.17	-1.70
cgy =	0.60	0.88	0.65	0.66	1.57	1.51	1.69	0.76	1.02	1.05	1.08
cgyn =	-0.70	-1.27	-0.91	-1.43	-2.14	-2.08	-2.59	-1.46	-1.04	-1.81	-1.40
cgz =	0.97	0.96	1.73	1.49	2.32	1.90	4.05	2.32	2.41	2.50	2.93
cgzn =	-1.54	-1.50	-1.68	-1.95	-2.80	-2.11	-3.08	-1.77	-1.73	-1.84	-1.88
drvr =	1.04	1.14	1.71	1.78	2.14	1.81	3.72	2.28	7.19	2.20	2.68
drvrn =	-1.37	-1.51	-1.60	-1.62	-2.21	-2.05	-2.58	-3.94	-4.34	-3.45	-1.63
ptch =	0.00	39.24	56.82	57.92	55.43	63.15	64.95	65.49	56.22	69.42	84.90
ptchn =	-5.90	-41.27	-55.27	-47.07	-57.32	-54.50	-68.60	-47.73	-51.68	-46.18	-52.65
roll =	11.06	10.29	13.17	16.83	20.71	19.41	34.94	19.40	28.80	16.32	18.10
rolln =	-9.84	-12.91	-11.33	-13.04	-15.43	-18.09	-30.15	-25.51	-23.91	-20.30	-16.80
yaw =	3.56	3.74	4.48	4.86	6.59	5.62	12.13	9.23	6.46	7.02	5.69
yawn =	-3.05	-5.03	-5.00	-3.76	-7.21	-4.82	-11.89	-7.27	-5.07	-22.52	-5.44
ster =	1.47	1.46	1.27	1.94	1.33	1.62	1.94	1.97	1.86	3.20	2.31
stern =	-1.80	-1.52	-1.67	-1.89	-2.21	-1.86	-3.54	-2.26	-2.13	-26.03	-2.97
lfrt =	4.46	4.45	4.96	4.95	5.02	5.05	5.10	4.89	4.92	4.96	4.89
lfrtn =	-4.41	-4.47	-4.11	-3.34	-4.15	-3.38	-3.45	-4.61	-4.52	-4.61	-4.77
lrr =	3.76	4.03	5.02	5.14	5.25	5.22	5.39	4.96	4.98	4.96	5.04
lrrn =	-2.87	-3.26	-3.61	-3.52	-4.13	-3.92	-4.23	-4.12	-4.18	-4.10	-3.85
rfrt =	4.57	4.63	4.78	4.83	4.91	4.88	4.95	4.80	4.81	4.81	4.81
rfrtn =	-4.01	-4.19	-3.77	-3.30	-4.05	-3.89	-3.68	-4.23	-4.19	-4.45	-4.58
rrr =	3.99	3.62	4.89	4.87	5.12	5.03	5.21	5.27	5.21	5.22	5.32
rrrn =	-2.93	-2.69	-4.09	-3.82	-4.49	-4.33	-4.71	-4.24	-4.25	-4.19	-3.81
spd =	15.80	15.87	20.50	20.49	25.34	25.29	31.24	11.11	10.06	11.62	13.22
runtime =	43.89	43.26	33.73	34.45	27.57	27.76	22.85	64.33	72.91	68.20	52.77

Test HMMWV Lane Change Maximum and Minimum

TEST	2400	24001	24002	24003	24004	24005	24006	24007	24008	24009	24010
frntx =	0.48	0.48	0.58	0.82	1.01	0.61	0.94	0.86	1.01	0.75	1.58
frntxn =	-0.41	-0.37	-0.73	-0.75	-0.82	-0.63	-0.70	-0.68	-0.66	-0.65	-1.09
frnty =	0.56	0.49	0.59	0.77	0.82	0.71	1.02	0.92	0.99	1.00	2.82
frntyn =	-0.46	-0.55	-0.74	-0.86	-0.95	-0.84	-1.05	-1.28	-1.23	-1.40	-4.07
frntz =	0.57	0.61	1.00	1.24	1.32	0.90	1.12	1.41	1.56	1.23	4.54
frntzn =	-0.57	-0.78	-1.13	-1.32	-1.23	-1.00	-1.06	-1.25	-1.52	-1.06	-4.67
cgx =	0.18	0.13	0.13	0.14	0.17	0.13	0.18	0.17	0.18	0.23	0.18
cgxn =	-0.13	-0.13	-0.12	-0.16	-0.14	-0.19	-0.20	-0.27	-0.22	-0.22	-0.19
cgy =	0.31	0.28	0.31	0.38	0.46	0.54	0.66	0.79	0.69	0.70	0.73
cgyn =	-0.21	-0.26	-0.31	-0.39	-0.47	-0.53	-0.65	-0.82	-0.76	-0.74	-0.70
cgz =	0.32	0.24	0.22	0.26	0.32	0.24	0.36	0.39	0.45	0.41	0.32
cgzn =	-0.23	-0.20	-0.23	-0.27	-0.33	-0.26	-0.36	-0.35	-0.46	-0.39	-0.42
drvr =	0.15	0.14	0.16	0.17	0.15	0.16	0.19	0.25	0.19	0.18	0.18
drvrn =	-0.18	-0.16	-0.18	-0.17	-0.17	-0.21	-0.22	-0.26	-0.26	-0.27	-0.33
ptch =	1.62	1.71	1.54	1.54	2.03	2.66	2.22	1.99	2.21	3.16	2.44
ptchn =	-1.37	-1.06	-1.28	-1.42	-2.53	-1.58	-2.68	-1.86	-2.99	-2.45	-2.82
roll =	4.08	2.97	3.73	4.40	6.93	8.09	11.13	14.40	15.69	16.30	15.46
rolln =	-2.76	-3.84	-5.89	-5.86	-6.80	-11.89	-18.66	-18.13	-16.87	-18.53	-10.93
yaw =	11.66	11.63	12.41	13.40	13.09	15.96	18.61	17.78	17.41	16.93	13.81
yawn =	-19.25	-12.84	-11.06	-11.43	-12.83	-13.63	-14.87	-15.71	-16.08	-15.68	-17.08
ster =	7.32	4.81	4.15	3.62	3.03	3.22	3.42	3.56	3.27	3.19	2.87
stern =	-13.33	-6.38	-4.81	-4.32	-4.74	-4.46	-4.32	-4.95	-4.56	-5.38	-4.51
lfrt =	0.35	0.57	0.79	0.92	1.44	1.59	2.66	2.34	2.28	2.59	1.93
lfrtn =	-0.14	-0.24	-0.46	-0.48	-0.48	-0.89	-0.80	-1.00	-1.01	-0.95	-1.12
lrr =	0.47	0.71	0.63	0.58	0.86	0.95	1.62	1.63	1.39	1.58	1.32
lrrn =	-0.25	-0.42	-0.41	-1.03	-0.85	-1.57	-1.49	-2.02	-1.89	-2.14	-1.86
rfrt =	0.56	0.62	0.83	1.02	1.19	1.66	1.97	3.03	2.69	3.33	2.94
rfrtn =	-0.50	-0.41	-0.59	-0.71	-1.04	-0.87	-1.67	-1.38	-1.43	-1.26	-1.22
rrr =	0.19	0.27	0.46	0.46	0.58	1.00	1.15	1.42	1.55	1.56	1.77
rrrn =	-0.66	-0.65	-0.81	-0.96	-1.43	-1.42	-2.14	-1.71	-1.82	-1.99	-1.69
spd =	10.64	16.21	19.91	25.75	29.45	35.29	40.60	43.16	42.84	46.12	45.88
runtime =	25.25	16.63	14.00	10.95	9.86	8.43	7.26	9.88	7.19	8.46	6.75

Test HMMWV Slalom Maximum and Minimum

TEST	23006	23007	23008	23009	23010	23011	23012	23013	23014	23015	23016
frntx =	0.41	0.48	0.49	0.79	0.55	0.81	0.93	0.84	0.73	1.98	0.71
frntxn =	-0.42	-0.52	-0.61	-0.94	-0.62	-0.90	-0.98	-0.84	-1.02	-5.33	-0.81
frnty =	0.45	0.57	0.65	0.92	0.67	0.84	0.96	1.16	1.13	2.32	1.22
frntyn =	-0.43	-0.54	-0.63	-1.05	-0.83	-0.97	-1.01	-1.07	-1.26	-3.30	-1.47
frntz =	0.60	0.66	0.81	1.51	1.09	1.69	2.25	1.25	1.86	2.67	1.50
frntzn =	-0.62	-0.62	-0.93	-1.48	-1.18	-1.37	-1.35	-1.10	-2.04	-2.19	-1.19
cgx =	0.17	0.11	0.12	0.13	0.12	0.14	0.18	0.21	0.27	0.42	0.35
cgxn =	-0.16	-0.14	-0.14	-0.15	-0.08	-0.13	-0.14	-0.15	-0.25	-0.24	-0.49
cgy =	0.22	0.29	0.34	0.45	0.39	0.47	0.64	0.77	0.71	0.82	1.18
cgyn =	-0.21	-0.29	-0.33	-0.41	-0.35	-0.45	-0.55	-0.68	-0.71	-0.86	-0.97
cgz =	0.25	0.24	0.22	0.31	0.17	0.27	0.32	0.31	0.37	0.67	0.66
cgzn =	-0.23	-0.23	-0.18	-0.31	-0.18	-0.27	-0.31	-0.35	-0.38	-0.48	-0.71
drvr =	0.16	0.15	0.18	0.17	0.20	0.16	0.17	0.16	0.15	0.20	0.53
drvrn =	-0.19	-0.21	-0.19	-0.18	-0.19	-0.18	-0.20	-0.27	-0.24	-0.31	-0.43
ptch =	1.66	2.23	2.66	2.27	1.64	2.85	3.02	3.63	3.50	5.02	3.55
ptchn =	-1.02	-1.02	-1.16	-1.78	-1.54	-1.84	-1.62	-1.44	-2.20	-3.21	-2.06
roll =	1.89	2.16	3.75	4.70	3.69	5.22	8.25	16.42	16.74	18.14	20.16
rolln =	-2.22	-2.89	-3.64	-4.36	-3.81	-5.48	-6.94	-19.05	-17.47	-27.43	-20.61
yaw =	8.79	12.42	13.57	15.50	13.32	15.76	16.63	20.31	23.22	26.98	19.57
yawn =	-8.98	-11.83	-12.70	-16.33	-14.64	-16.92	-19.47	-26.80	-21.23	-27.09	-17.94
ster =	6.78	6.84	6.18	6.48	4.50	4.51	4.25	5.25	5.55	6.63	4.10
stern =	-4.71	-4.46	-3.95	-4.43	-5.58	-5.18	-6.97	-8.43	-8.39	-11.35	-5.66
lfrt =	-0.05	0.19	0.57	0.96	0.72	1.06	2.81	4.49	3.76	4.59	4.04
lfrtn =	-0.53	-0.79	-0.91	-0.90	-0.49	-0.70	-0.65	-0.33	-0.56	-0.62	-0.60
lrr =	-0.44	-0.40	-0.41	-0.13	0.63	1.10	0.89	2.09	1.15	2.30	1.72
lrrn =	-1.13	-1.32	-1.32	-1.51	-0.63	-0.90	-1.49	-2.22	-2.19	-2.47	-2.46
rfrt =	-0.02	0.10	0.15	0.41	0.65	0.96	2.56	3.65	3.54	4.77	4.83
rfrtn =	-0.89	-0.88	-0.98	-1.06	-0.65	-0.87	-0.19	-0.72	-0.58	-0.71	-0.59
rrr =	-0.33	-0.15	-0.18	-0.04	0.31	0.63	1.14	0.89	1.44	2.45	1.46
rrrn =	-0.77	-1.08	-1.18	-1.82	-0.80	-0.85	-2.11	-2.74	-2.75	-3.08	-2.54
spd =	10.65	15.59	19.95	24.25	21.18	25.43	29.91	33.67	33.06	35.01	40.42
runtime =	52.27	36.50	28.99	23.81	26.57	21.71	18.44	16.94	21.57	22.38	17.61

Passive HMMWV RMS Maximum and Minimum

Passive	26000	26001	26002	26003	26004	26005	26006	26007	26008	24010	24011
frntx =	0.86	1.22	2.25	1.42	2.61	3.42	3.49	3.29	2.51	0.86	0.86
frntxn =	-0.84	-1.01	-2.95	-3.19	-3.19	-5.36	-5.47	-5.40	-2.93	-0.80	-0.89
frnty =	0.66	0.69	3.45	2.25	2.86	5.12	4.59	4.85	4.72	0.73	0.88
frntyn =	-1.19	-0.87	-2.62	-2.31	-3.89	-6.75	-7.46	-8.53	-3.31	-0.91	-0.95
frntz =	2.14	2.54	5.53	5.25	6.54	11.72	11.24	10.87	7.17	2.08	2.14
frntzn =	-2.12	-1.79	-3.89	-4.77	-7.22	-7.17	-6.12	-8.48	-8.19	-1.75	-2.07
cgx =	0.25	0.23	0.45	0.35	0.65	0.71	1.11	1.01	0.95	0.41	1.65
cgxn =	-0.28	-0.28	-0.70	-0.55	-0.82	-0.97	-0.89	-1.06	-1.17	-0.24	-0.66
cgy =	0.25	0.23	0.26	0.27	0.40	0.39	0.65	0.56	0.58	0.26	0.91
cgyn =	-0.22	-0.22	-0.28	-0.27	-0.39	-0.44	-0.45	-0.50	-0.52	-0.46	-1.03
cgz =	0.94	1.06	1.00	1.26	2.04	1.62	1.82	2.42	2.29	0.80	1.55
cgzn =	-0.90	-0.91	-0.99	-0.93	-1.08	-1.13	-1.97	-1.82	-1.39	-0.99	-2.21
drvr =	1.00	1.07	1.12	1.35	1.96	2.15	2.59	3.24	3.37	0.87	1.59
drvrn =	-0.91	-0.99	-1.05	-1.21	-1.81	-1.52	-2.64	-2.47	-1.55	-0.95	-2.70
ptch =	31.09	33.72	51.49	44.84	61.86	76.09	71.48	72.01	61.15	23.91	35.57
ptchn =	-33.87	-36.05	-47.25	-53.94	-74.03	-66.78	-78.97	-66.83	-71.48	-30.71	-36.06
roll =	11.74	14.01	15.26	16.21	20.27	21.91	27.08	23.37	25.42	11.27	16.90
rolln =	-12.09	-11.28	-18.60	-17.32	-21.93	-18.37	-33.49	-27.54	-27.26	-9.91	-17.29
yaw =	3.03	4.25	3.94	5.04	5.67	4.42	7.32	6.50	6.26	4.19	4.99
yawn =	-3.52	-3.50	-4.29	-4.55	-6.77	-5.47	-8.94	-9.81	-6.20	-6.48	-4.86
ster =	0.69	0.65	1.01	0.92	1.76	2.12	2.12	2.29	5.84	2.40	2.38
stern =	-1.33	-1.13	-1.79	-1.69	-1.21	-1.71	-1.77	-1.95	-2.07	-4.66	-4.77
lfrt =	3.21	3.75	4.26	4.38	4.65	4.65	4.81	4.88	4.61	3.13	3.68
lfrtn =	-2.40	-2.51	-2.96	-3.00	-3.10	-3.20	-3.16	-3.25	-3.07	-2.48	-2.76
lrr =	2.38	2.42	2.43	2.46	2.38	2.42	2.65	2.64	2.21	2.32	2.42
lrrn =	-2.13	-2.39	-2.33	-2.50	-2.86	-3.05	-3.89	-3.95	-5.03	-1.85	-2.27
rfrt =	3.75	3.67	4.08	4.17	4.21	4.35	4.44	4.58	3.55	3.65	3.38
rfrtn =	-2.53	-2.44	-2.87	-3.18	-3.31	-3.30	-3.26	-3.33	-3.91	-2.53	-2.60
rrr =	2.52	2.62	2.64	2.68	2.76	2.77	2.94	2.95	2.90	2.50	2.66
rrrn =	-2.27	-2.55	-2.19	-2.57	-2.67	-2.97	-3.80	-3.87	-4.38	-1.85	-2.54
spd =	11.13	11.42	15.48	15.54	20.48	20.28	26.22	25.64	10.30	10.33	10.49
runtime =	63.05	59.82	44.37	44.31	33.71	34.38	26.40	28.64	70.49	67.51	68.88

Passive HMMWV RMS Maximum and Minimum continued

Passive	24012	24013	24014	24015	24016	24017	24018	24020
frntx =	0.95	1.52	1.57	1.69	1.48	2.36	2.07	
frntxn =	-0.99	-1.97	-1.74	-1.74	-1.67	-2.43	-2.77	
frnty =	1.02	1.91	1.59	2.66	2.66	3.12	3.94	
frntyn =	-1.35	-1.61	-1.65	-2.16	-2.58	-2.90	-4.11	
frntz =	2.51	3.19	4.96	5.01	7.25	7.44	8.31	
frntzn =	-3.04	-3.94	-4.99	-6.48	-7.03	-6.77	-8.92	
cgx =	2.20	2.46	0.67	2.38	2.83	2.63	2.79	
cgxn =	-1.41	-1.47	-0.49	-1.59	-2.08	-2.07	-2.14	
cgy =	0.96	1.46	0.85	1.83	1.88	1.88	2.64	
cgyn =	-1.57	-2.54	-1.03	-2.54	-2.58	-2.75	-2.81	
cgz =	1.57	1.66	1.21	1.74	1.67	1.87	1.81	
cgzn =	-2.87	-3.15	-1.65	-2.85	-3.30	-3.57	-3.36	
drvr =	2.40	2.86	1.12	2.97	3.65	4.78	3.99	
drvrn =	-3.60	-2.26	-1.26	-3.40	-7.40	-8.52	-9.61	
ptch =	31.04	42.03	36.23	45.63	53.80	50.21	63.02	
ptchn =	-45.95	-46.94	-42.83	-52.68	-60.94	-65.09	-57.97	
roll =	15.56	18.11	18.52	20.99	20.33	22.04	20.77	
rolln =	-13.14	-19.02	-14.76	-21.13	-19.41	-22.98	-25.48	
yaw =	5.24	4.68	4.24	8.18	5.49	7.27	9.88	
yawn =	-4.33	-5.12	-5.26	-4.93	-6.85	-6.05	-7.85	
ster =	2.75	2.40	2.46	3.21	2.50	2.83	3.39	
stern =	-4.35	-4.61	-3.32	-3.15	-3.11	-2.90	-3.38	
lfrt =	4.15	4.32	3.10	3.49	2.98	4.08	3.81	
lfrtn =	-2.68	-3.02	-3.13	-3.13	-3.22	-3.12	-3.81	
lrr =	2.49	2.55	2.11	2.53	2.64	2.61	2.75	
lrrn =	-2.34	-2.46	-2.50	-2.45	-2.79	-2.51	-3.30	
rfrt =	4.00	4.20	3.51	3.91	3.61	4.17	4.07	4.22
rfrtn =	-2.69	-3.09	-2.90	-2.96	-3.05	-2.88	-3.45	-3.21
rrr =	2.64	2.64	1.97	2.38	2.59	2.63	2.79	2.83
rrrn =	-2.47	-2.51	-2.81	-3.20	-2.90	-3.39	-3.70	-3.55
spd =	15.32	15.52	20.41	20.35	25.16	24.98	29.90	29.30
runtime =	47.35	45.23	35.85	36.07	28.52	28.35	24.70	

Passive HMMWV Lane Change Maximum and Minimum

PASSIVE	24000	24001	24002	24003	24004	24005	24006	24007	24008	24009
frntx =	0.42	0.37	0.52	0.49	0.56	0.55	0.75	0.54	0.74	1.14
frntxn =	-0.50	-0.42	-0.50	-0.54	-0.61	-0.56	-0.66	-0.62	-0.63	-0.87
frnty =	0.36	0.38	0.60	0.59	0.70	0.86	0.86	0.79	0.88	1.06
frntyn =	-0.32	-0.42	-0.51	-0.58	-0.65	-0.83	-0.68	-0.87	-0.92	-1.95
frntz =	0.65	0.66	1.61	1.08	1.30	0.97	1.16	0.87	1.06	3.89
frntzn =	-0.61	-0.90	-1.26	-1.00	-1.31	-1.12	-1.19	-1.01	-1.13	-3.96
cgx =	0.08	0.08	0.10	0.10	0.12	0.12	0.15	0.14	0.11	0.14
cgxn =	-0.06	-0.08	-0.07	-0.12	-0.07	-0.09	-0.10	-0.11	-0.10	-0.15
cgy =	0.18	0.20	0.22	0.30	0.38	0.44	0.52	0.48	0.59	0.62
cgyn =	-0.14	-0.20	-0.28	-0.27	-0.42	-0.46	-0.38	-0.51	-0.55	-0.59
cgz =	0.16	0.13	0.16	0.17	0.19	0.15	0.19	0.19	0.17	0.21
cgzn =	-0.13	-0.12	-0.13	-0.18	-0.14	-0.15	-0.15	-0.18	-0.19	-0.20
drvr =	0.12	0.13	0.14	0.13	0.12	0.16	0.21	0.19	0.17	0.23
drvrn =	-0.17	-0.16	-0.22	-0.25	-0.27	-0.33	-0.36	-0.35	-0.32	-0.41
ptch =	2.57	3.23	3.35	3.30	3.19	3.30	2.87	3.22	3.25	4.16
ptchn =	-1.94	-2.60	-1.98	-2.06	-1.85	-1.75	-2.62	-2.06	-2.65	-2.44
roll =	3.98	3.28	4.65	4.25	6.76	6.73	9.46	8.93	10.77	10.98
rolln =	-2.63	-3.57	-5.70	-3.94	-6.39	-6.89	-6.91	-9.42	-9.20	-10.42
yaw =	10.22	11.27	12.77	10.75	15.65	16.69	11.41	15.23	16.57	15.04
yawn =	-11.98	-11.78	-11.32	-11.45	-13.82	-16.31	-16.86	-15.42	-17.67	-18.07
ster =	6.90	6.02	4.86	3.70	4.67	4.34	3.06	3.67	4.14	3.58
stern =	-8.10	-6.33	-5.90	-5.49	-5.75	-5.88	-5.89	-5.52	-5.82	-5.87
lfrt =	0.30	0.37	0.39	0.57	0.69	0.98	1.13	1.19	1.37	1.50
lfrtn =	-0.33	-0.44	-0.48	-0.48	-0.60	-0.66	-0.59	-0.77	-0.68	-0.89
lrr =	0.21	0.32	0.33	0.39	0.48	0.69	0.91	0.85	1.06	1.15
lrrn =	-0.28	-0.36	-0.43	-0.42	-0.60	-0.77	-0.63	-0.74	-0.84	-0.80
rfrt =	0.18	0.26	0.37	0.39	0.65	0.79	0.64	0.83	1.13	1.05
rfrtn =	-0.34	-0.43	-0.46	-0.49	-0.57	-0.61	-0.67	-0.65	-0.68	-0.67
rrr =	0.12	0.24	0.29	0.33	0.53	0.65	0.47	0.74	0.87	0.85
rrrn =	-0.34	-0.44	-0.47	-0.50	-0.67	-0.67	-0.83	-0.70	-0.79	-0.85
spd =	11.42	16.15	21.17	25.73	29.38	36.05	40.20	42.43	47.36	51.46
runtime =	23.20	16.19	12.81	11.07	9.75	7.56	7.68	6.49	7.02	6.87

Passive HMMWV Slalom Maximum and Minimum

PASSIVE	23006	23007	23008	23009	23010	23011	23012
frntx =	0.35	0.39	0.41	0.57	0.55	0.53	0.71
frntxn =	-0.36	-0.44	-0.59	-0.66	-0.70	-0.67	-0.95
frnty =	0.36	0.43	0.62	0.76	0.76	1.08	1.24
frntyn =	-0.35	-0.56	-0.72	-0.94	-0.87	-1.12	-1.37
frntz =	0.74	0.78	1.76	1.43	1.41	1.06	1.79
frntzn =	-0.66	-0.91	-1.28	-1.61	-1.45	-1.35	-1.64
cgx =	0.06	0.05	0.11	0.10	0.10	0.11	0.47
cgxn =	-0.05	-0.08	-0.12	-0.14	-0.10	-0.13	-0.26
cgy =	0.13	0.21	0.32	0.38	0.53	0.72	0.77
cgyn =	-0.15	-0.19	-0.32	-0.41	-0.51	-0.64	-0.94
cgz =	0.12	0.17	0.20	0.20	0.18	0.20	0.34
cgzn =	-0.11	-0.13	-0.18	-0.17	-0.21	-0.22	-0.46
drvr =	0.15	0.20	0.22	0.30	0.27	0.29	0.30
drvrn =	-0.13	-0.17	-0.19	-0.22	-0.23	-0.32	-0.46
ptch =	2.80	2.57	2.81	3.64	3.86	4.63	4.49
ptchn =	-2.29	-2.52	-3.01	-2.71	-2.69	-2.02	-2.75
roll =	3.35	3.66	5.91	6.92	7.66	12.96	16.79
rolln =	-3.25	-4.06	-4.58	-5.54	-6.25	-8.51	-12.05
yaw =	8.25	10.86	14.89	17.96	18.74	22.26	26.54
yawn =	-8.81	-11.68	-14.35	-16.90	-19.88	-26.43	-32.13
ster =	7.14	6.61	7.49	7.41	7.00	7.35	9.22
stern =	-5.84	-5.49	-5.45	-5.33	-5.84	-6.69	-8.06
lfrt =	0.10	0.21	0.36	0.59	1.03	1.75	1.88
lfrtn =	-0.35	-0.43	-0.68	-0.73	-0.78	-0.87	-1.00
lrr =	0.17	0.32	0.46	0.64	0.87	1.51	1.83
lrrn =	-0.23	-0.33	-0.53	-0.63	-0.70	-0.85	-0.92
rfrt =	0.13	0.18	0.39	0.60	0.88	1.23	1.82
rfrtn =	-0.36	-0.45	-0.60	-0.70	-0.72	-0.96	-0.83
rrr =	0.12	0.20	0.39	0.58	0.75	1.07	1.33
rrrn =	-0.29	-0.36	-0.54	-0.58	-0.80	-0.94	-0.88
spd =	10.62	15.56	20.37	24.98	29.71	34.43	34.10
runtime =	1.22	1.79	2.55	3.25	3.73	4.37	4.31

APPENDIX E - Passive and Test HMMWV Absorbed Power Values

ACT/PAS	FILE	MIN	MAX	RMS	AVE.SPD	ABS POW	RUN TIME	DIREC.
ACT 24 RMS 3	011							S
ACT 24 RMS 3	012							N
ACT 24 RMS 3	013	-0.61	0.71	0.16	10.04	1.59	69.73	S
ACT 24 RMS 3	014	-1.04	1.20	0.21	10.34	1.54	69.01	N
ACT 24 RMS 3	015	-0.83	0.79	0.17	15.51	2.37	46.16	S
ACT 24 RMS 3	016	-1.60	0.79	0.17	15.17	2.60	47.61	N
ACT 24 RMS 3	017	-0.68	0.76	0.16	10.75	1.84	66.23	S
ACT 24 RMS 3	018	-1.69	1.05	0.24	14.86	3.82	46.99	N
ACT 24 RMS 3	019	-1.32	1.62	0.27	20.43	4.81	34.63	S
ACT 24 RMS 3	020	-1.67	3.07	0.28	20.39	5.29	35.37	N
ACT 24 RMS 3	021	-1.52	1.06	0.27	25.13	6.16	28.54	S
ACT 24 RMS 3	022	-1.64	1.97	0.33	25.05	9.92	29.02	N
ACT 24 RMS 3	023	-2.63	1.57	0.35	30.45	12.64	26.06	S
ACT 24 RMS 3	024	-2.00	1.68	0.39	30.92	16.52	25.11	N
ACT 24 RMS 3	025	-4.91	1.56	0.42	35.05	17.20	21.82	S
ACT 24 RMS 3	026	-1.74	1.81	0.46	34.46	21.38	24.12	N
ACT 24 RMS 3	027	-2.07	2.71	0.50	40.50	23.59	22.16	S
ACT 24 RMS 3	028	-2.61	6.19	0.55	40.82	27.16	18.01	N
ACT 24 RMS 3	029	-5.09	3.68	0.64	45.01	32.66	18.07	S
ACT 26 RMS 4	000	-1.03	0.97	0.33	11.29	2.67	61.17	N
ACT 26 RMS 4	001	-1.12	1.01	0.35	11.92	3.01	57.31	S
ACT 26 RMS 4	002	-1.36	1.04	0.35	15.81	4.53	43.89	N
ACT 26 RMS 4	003	-1.51	1.11	0.36	15.87	4.98	43.26	S
ACT 26 RMS 4	004	-1.60	1.71	0.36	20.46	7.54	33.73	S
ACT 26 RMS 4	005	-1.62	1.78	0.35	20.51	6.22	34.45	N
ACT 26 RMS 4	006	-2.21	2.14	0.50	25.31	17.05	27.57	S
ACT 26 RMS 4	007	-2.05	1.81	0.44	25.29	11.45	27.76	N
ACT 26 RMS 4	008	-2.58	3.72	0.66	31.20	32.76	22.85	S
ACT 26 RMS 5	009	-3.94	2.23	0.53	11.06	6.87	64.33	S
ACT 26 RMS 5	010	-3.43	7.19	0.50	10.09	5.90	72.91	N
ACT 26 RMS 5	011	-2.08	2.17	0.55	11.77	8.36	68.20	S
ACT 26 RMS 5	012	-1.60	2.68	0.54	13.20	9.10	52.77	N
PAS 24 RMS 3	010	-0.95	0.86	0.28	10.26	2.54	67.51	S
PAS 24 RMS 3	011	-2.70	1.59	0.32	10.46	3.42	68.88	N
PAS 24 RMS 3	012	-3.60	2.40	0.32	15.32	6.09	47.35	S
PAS 24 RMS 3	013	-2.22	2.86	0.36	15.50	7.85	45.23	N
PAS 24 RMS 3	014	-1.26	1.12	0.30	20.39	8.48	35.85	S
PAS 24 RMS 3	015	-3.40	2.97	0.37	20.23	11.49	36.07	N
PAS 24 RMS 3	016	-7.40	3.65	0.45	25.16	15.02	28.53	S
PAS 24 RMS 3	017	-8.52	4.78	0.57	24.98	20.45	28.35	N

Passive and Test HMMWV Absorbed Power Values continued

ACT/PAS	FILE	MIN	MAX	RMS	AVE.SPD	ABS POW	RUN TIME	DIREC.
PAS 24 RMS 3	018	-9.61	3.99	0.69	29.77	31.18	24.70	S
PAS 26 RMS 4	000	-0.91	1.00	0.31	11.15	3.29	63.05	N
PAS 26 RMS 4	001	-0.98	1.05	0.34	11.38	3.93	59.82	S
PAS 26 RMS 4	002	-1.02	1.12	0.34	15.48	6.06	44.37	N
PAS 26 RMS 4	003	-1.21	1.32	0.36	15.52	7.32	44.31	S
PAS 26 RMS 4	004	-1.81	1.96	0.37	20.42	11.41	33.71	S
PAS 26 RMS 4	005	-1.52	2.15	0.37	20.29	10.26	34.38	N
PAS 26 RMS 4	006	-2.64	2.59	0.58	26.22	27.81	26.40	S
PAS 26 RMS 4	007	-2.47	3.24	0.52	25.64	17.49	28.64	N
PAS 26 RMS 5	008	-1.55	3.34	0.46	10.31	6.98	70.49	S